

Quarkonia at LHC - probes for deconfined heavy quarks in relativistic nuclear collisions

- introduction
- charmonium data
 - (run1 completely analyzed)
- pPb data
- bottomonium

Johanna Stachel, Universität Heidelberg
11th International Workshop on High-pT Physics in the RHIC &LHC Era
Brookhaven National Laboratory, USA, April 12-15, 2016

charmonia as a probe of deconfinement

- the original idea: (Matsui and Satz 1986) implant charmonia into the QGP and observe their modification, in terms of suppressed production in nucleus-nucleus collisions with or without plasma formation → sequential melting
- new insight (Braun-Munzinger, J.S. 2000):
QGP screens all charmonia (as proposed by Matsui and Satz), but charmonium production takes place at the phase boundary,
 - enhanced production at colliders – signal for deconfinement
 - production probability from thermalized charm quarks scales with $N_{(cc\bar{c})}^2$
- alternative to statistical hadronization: implementation of screening into space-time evolution of the fireball → continuous destruction and (re)generation
Thews et al., 2001, Rapp et al. 2001, Gorenstein et al. 2001, P.F. Zhuang et al. 2005

formation time of quarkonia

heavy quark velocity in charmonium rest frame:

$v = 0.55$ for J/ψ see, e.g. G.T. Bodwin et al., hep-ph/0611002

minimum formation time: $t = \text{radius}/v = 0.45 \text{ fm}$

see also:

Hüfner, Ivanov, Kopeliovich, and Tarasov, Phys. Rev. D62 (2000) 094022

J.P. Blaizot and J.Y. Ollitrault, Phys. Rev. D39 (1989) 232

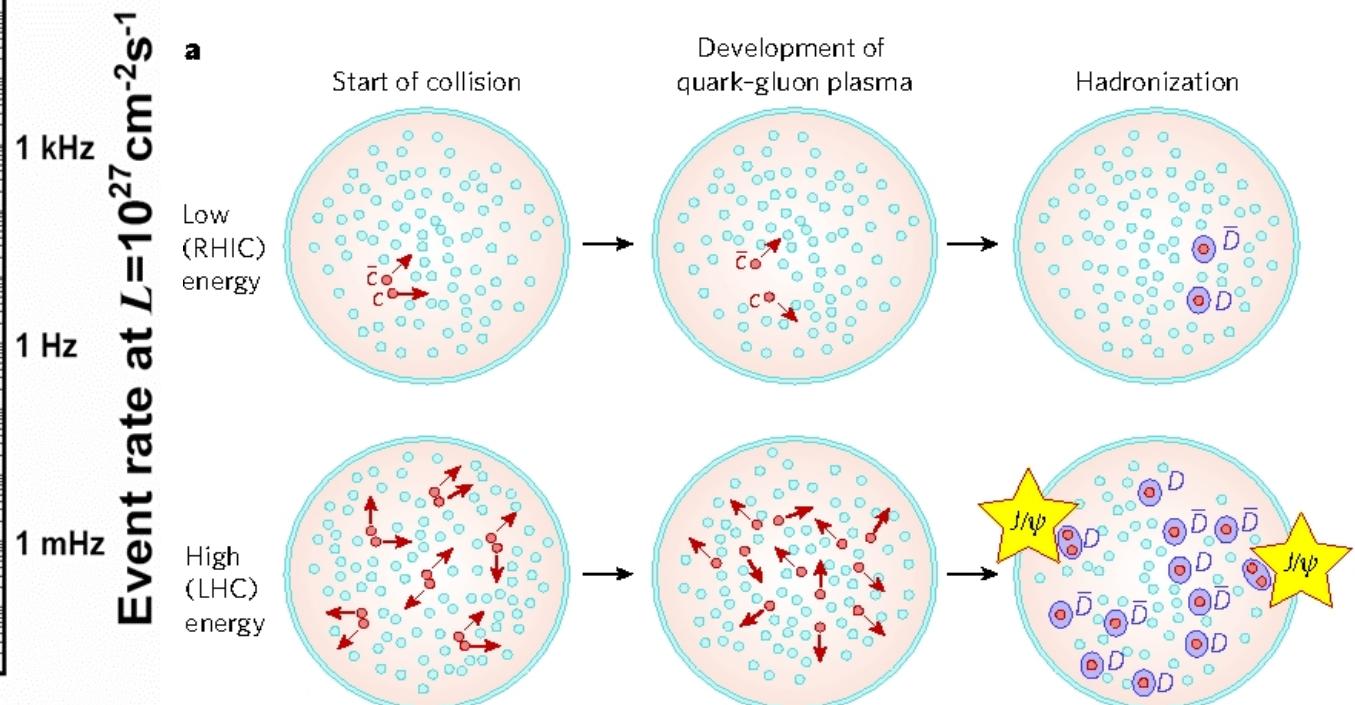
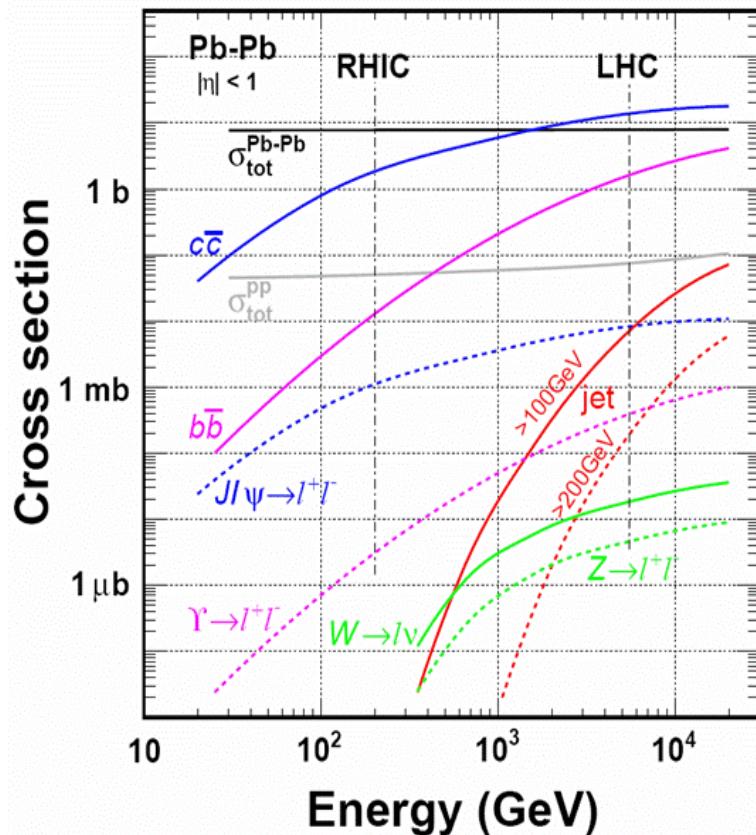
formation time of order 1 fm

formation time is not short compared to plasma formation time (especially at high energy)

implanting charmonia in hot medium is not appropriate notion

what happens to deconfined charm quarks at higher beam energy?

as more and more charm quarks produced, probability for c and cbar to hadronize into J/psi grows quadratically



low energy: few c-quarks per collision
high energy: many “ “

→ suppression of J/ψ
→ enhancement “
unambiguous signature for QGP!

needed input for statistical hadronization and for transport approach: total charm cross section

standard approach: reconstruct charmed hadrons from their weak decay products, try to cover spectral range down to 0, obtain charm cross section assuming some known fragmentation functions

difficulties:

- reach to very low p_t - to a lesser extent, rapidity coverage, extrapolation leads to systematic errors
- modifications in PbPb vs pp due to different parton distributions, use min. bias pPb as intermediate step, proxy for cold nuclear medium, largest contribution to syst.
- modifications due to QGP medium

no medium effect

charm conservation equation

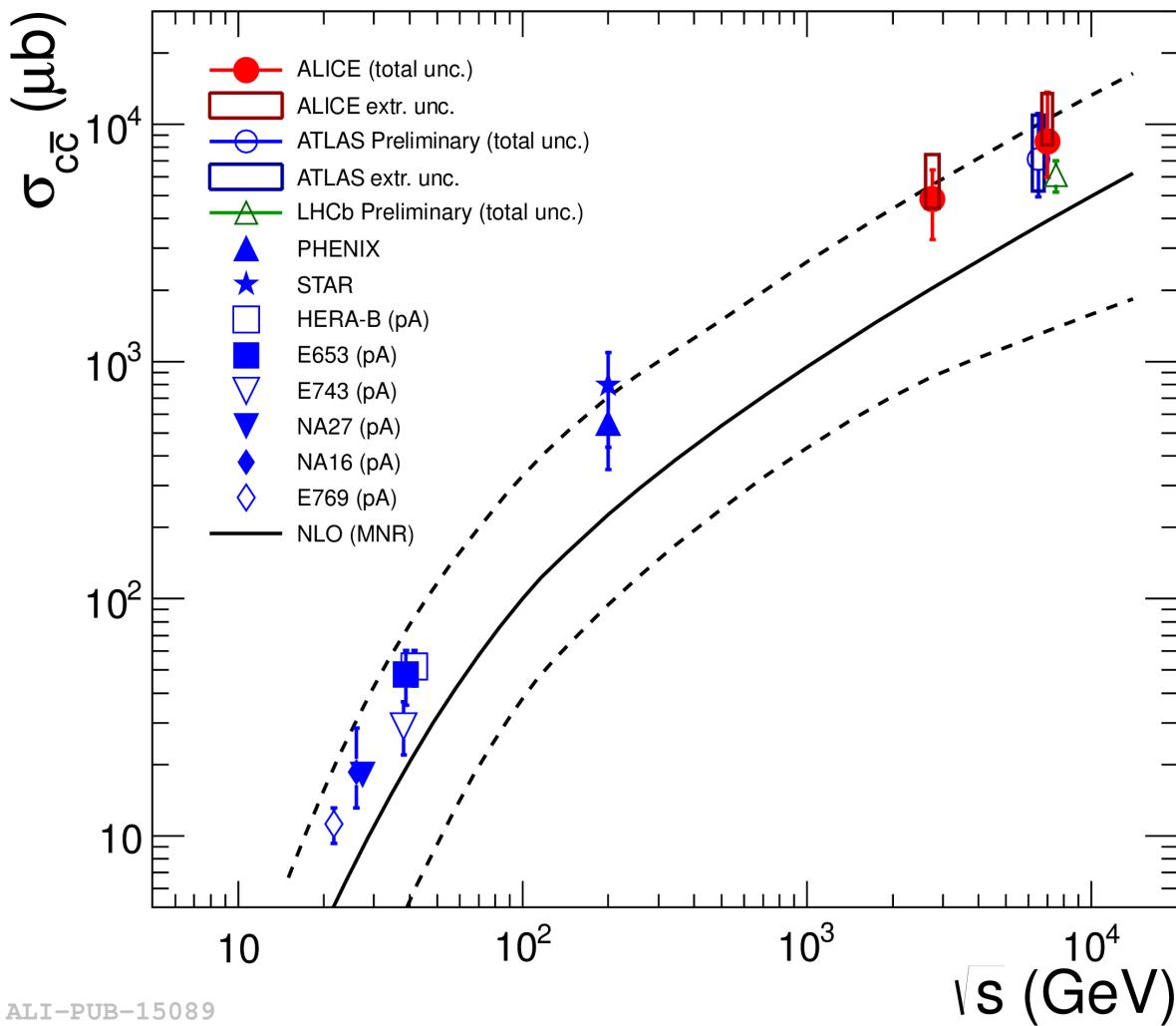
$$\sigma_{c\bar{c}} = 1/2 \left[\sigma_{D^+} + \sigma_{D^-} + \sigma_{D^0} + \sigma_{\bar{D}^0} + \sigma_{\Lambda_c} + \sigma_{\bar{\Lambda}_c} \dots \right]$$



medium effects on charmed hadrons affect redistribution of charm (among hadrons and in momentum), but not overall cross section

a first try at the total ccbar cross section in pp at LHC

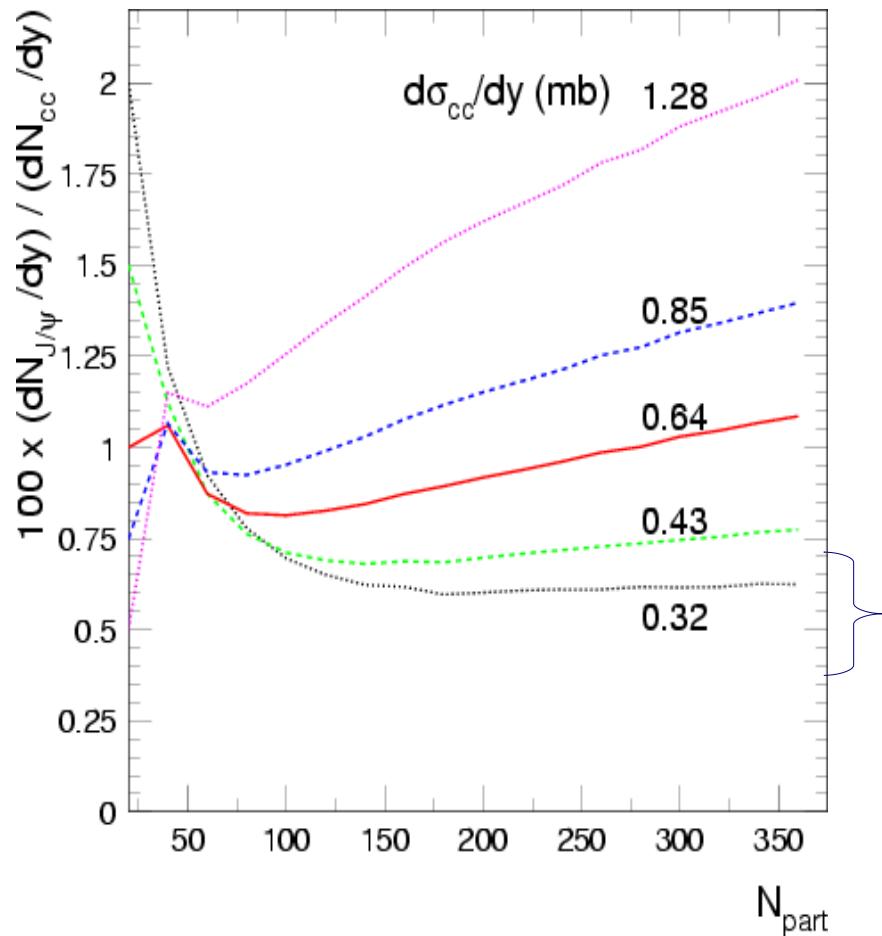
JHEP 1207 (2012) 191



- good agreement between ALICE, ATLAS and LHCb
- large syst. error due to extrapolation to low p_t , need to push measurements in that direction
- data factor 2 ± 0.5 above central value of FONLL but well within uncertainty
- beam energy dependence follows well FONLL

ALI-PUB-15089

predictions for LHC energies

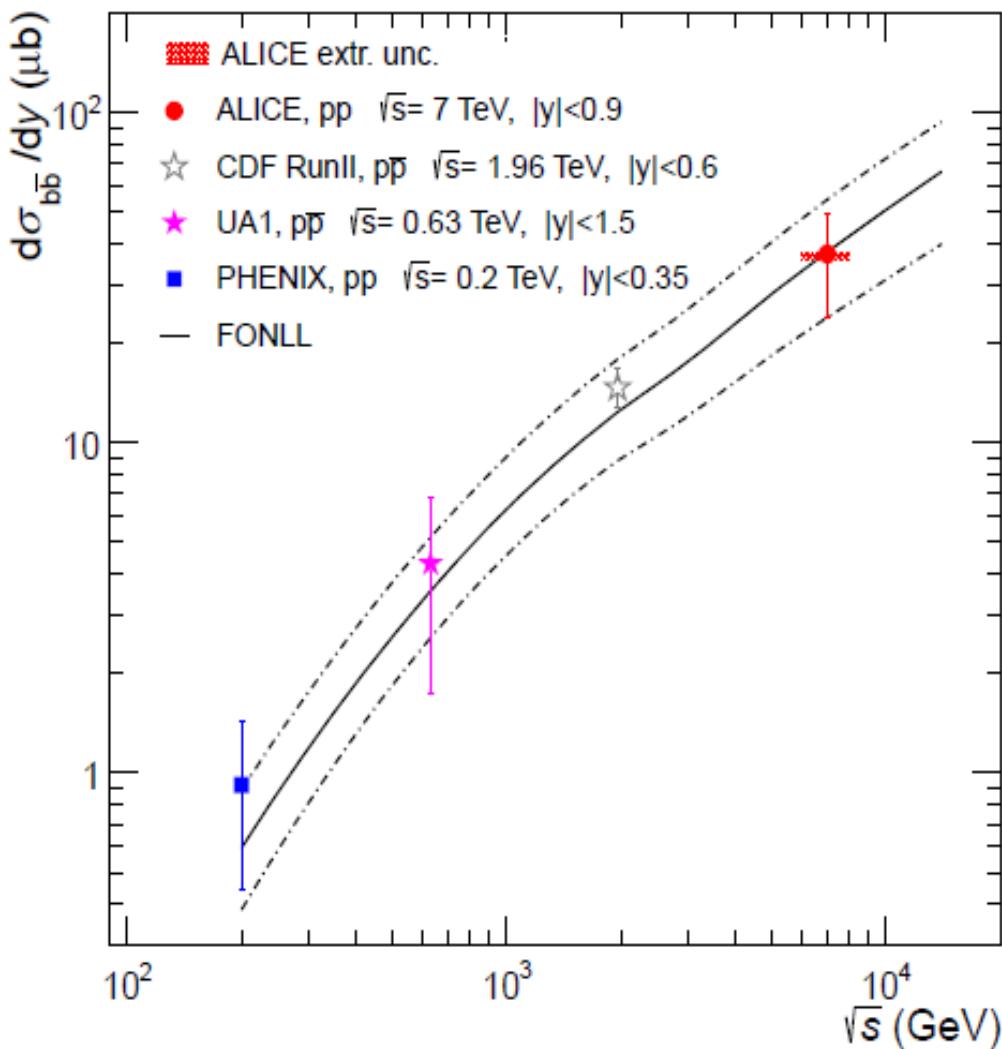


open charm is natural and essential
normalization
precision measurement needed

LHC 2.76 TeV including shadowing
(more below)

A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel Phys. Lett. B652 (2007) 259

Beauty cross section in pp and ppbar collisions



rapidity density of beauty cross section in excellent agreement with pQCD

total bbar cross section

$$\sigma_{b\bar{b}} = 280 \pm 23(\text{stat})^{+81}_{-79}(\text{sys})^{+7}_{-8}(\text{extr}) \pm 10(\text{BR}) \mu b,$$

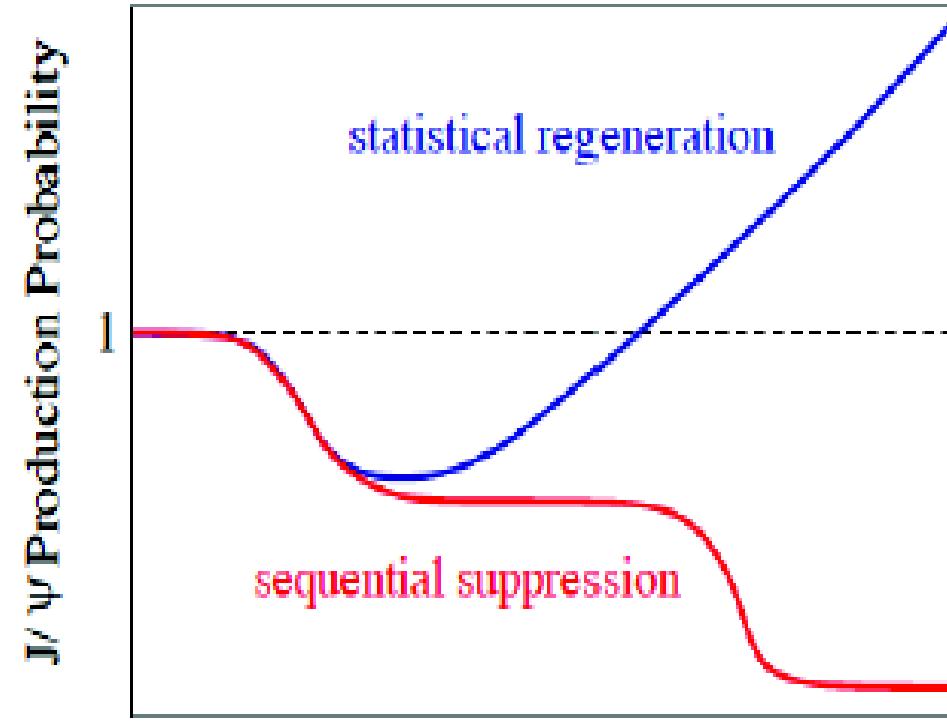
well consistent with ALICE measurement of J/psi from displaced secondary vertices

$$\sigma_{b\bar{b}} = 282 \pm 74(\text{stat})^{+58}_{-68}(\text{sys})^{+8}_{-7}(\text{extr}) \mu b$$

compared to FONLL

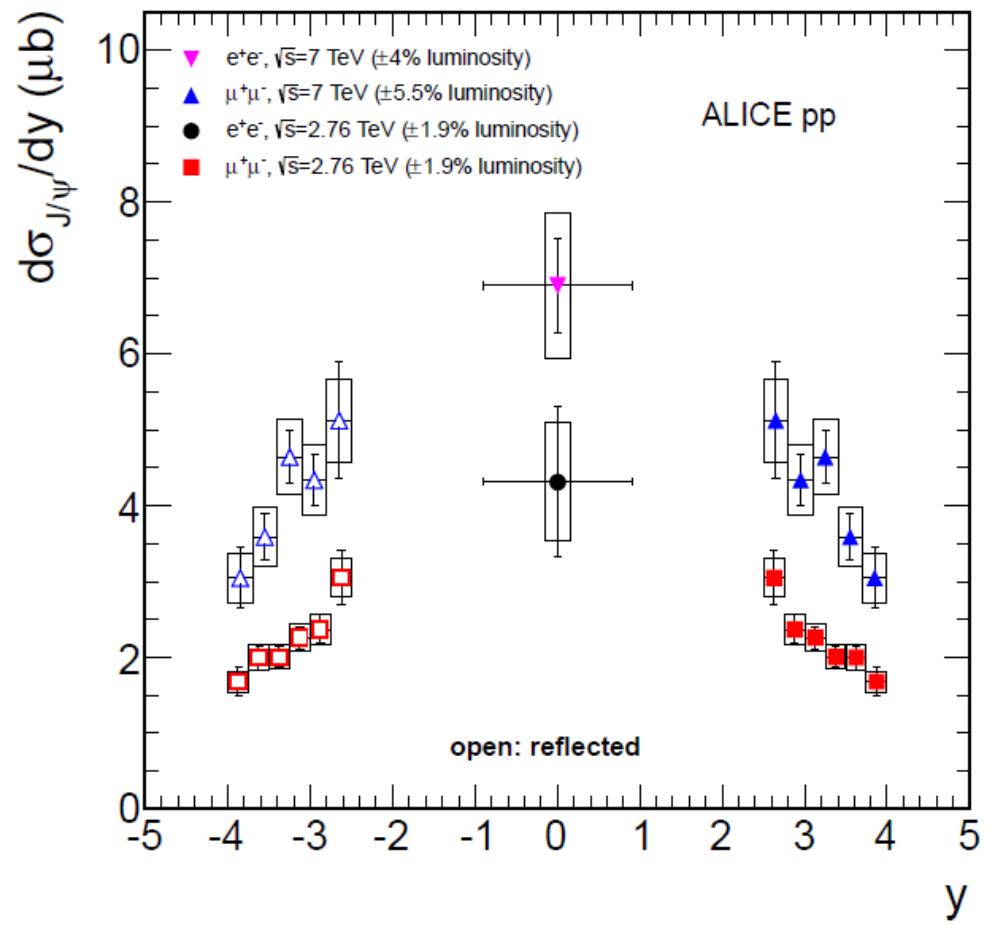
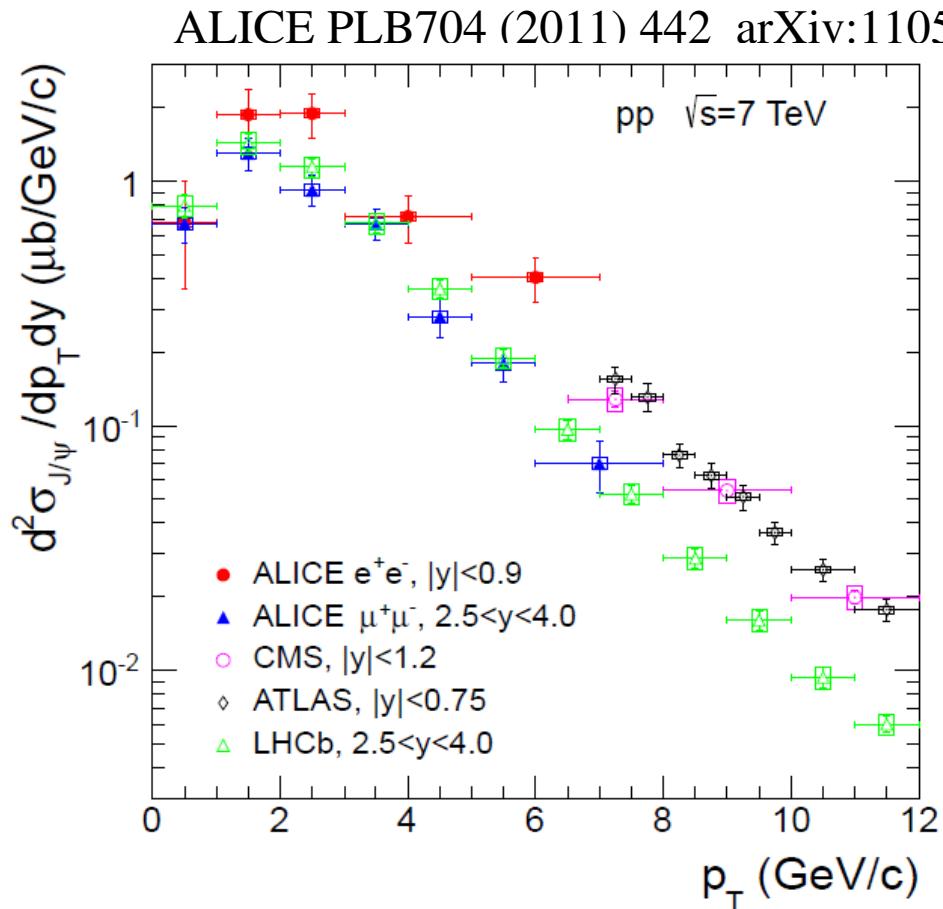
$$\sigma_{b\bar{b}} = 259^{+120}_{-96} \mu b$$

decision on regeneration vs. sequential suppression from LHC data



Picture:
H. Satz 2009

J/psi spectrum and cross section in pp collisions

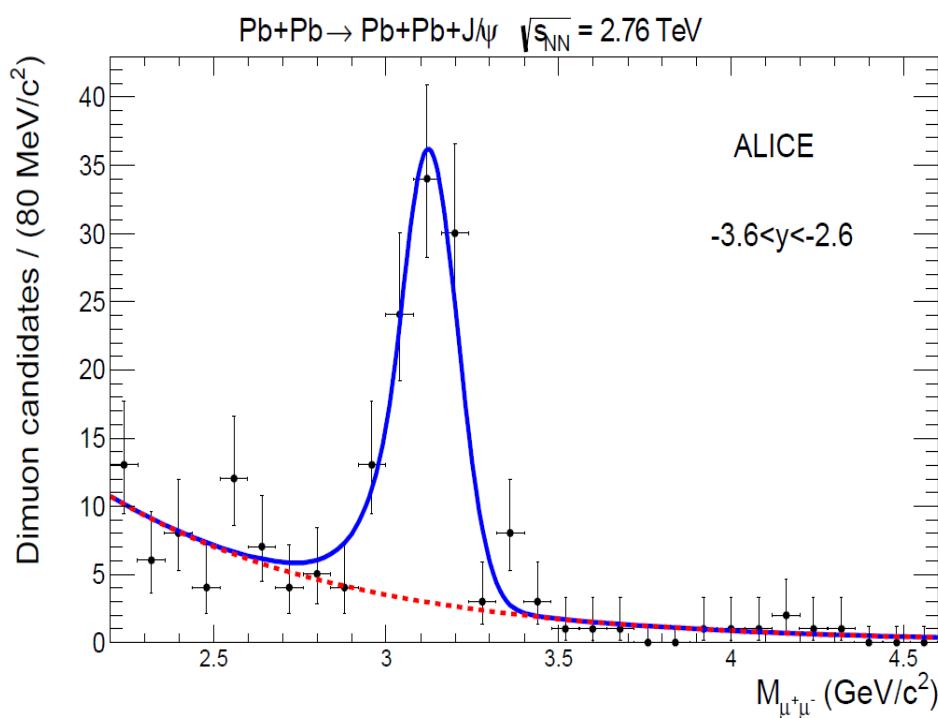


- good agreement between experiments
- complementary in acceptance:
only ALICE has acceptance below
6 GeV at mid-rapidity

measured both at 7 and 2.76 TeV
open issues: statistics at mid-rapidity
polarization (biggest source of syst error)

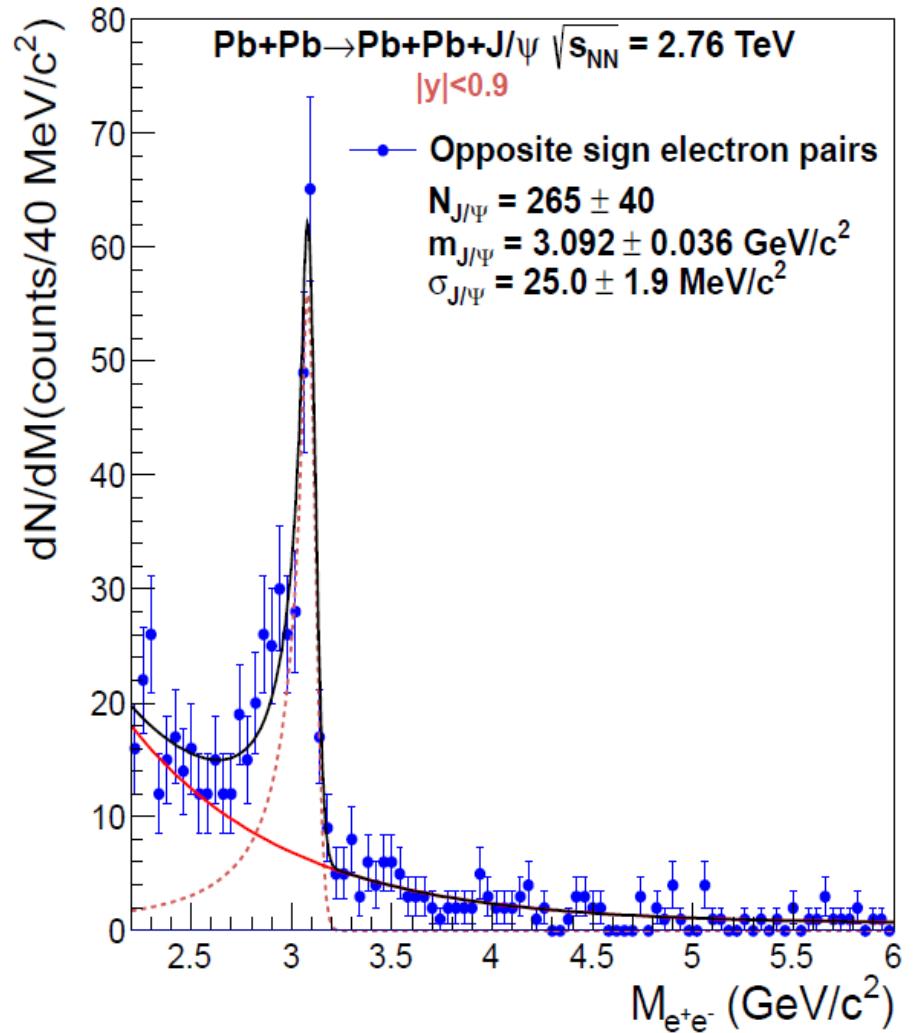
reconstruction of J/psi via mu+mu- and e+e- decay

PLB 718 arXiv:1209.3715

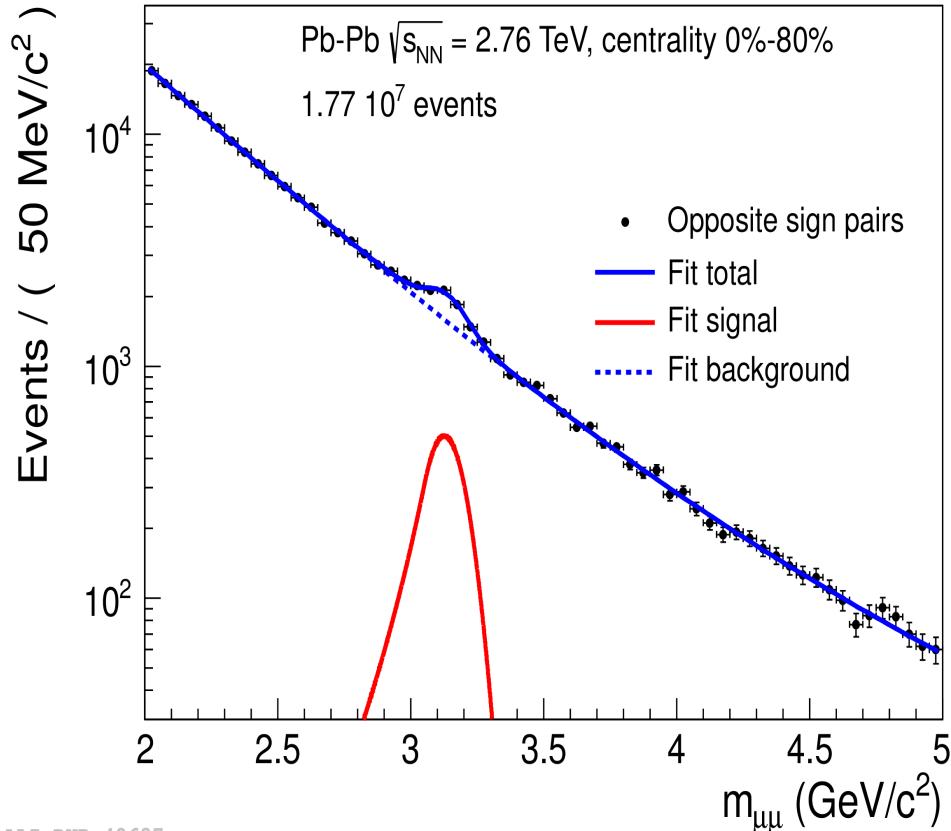


photoproduction in ultra-peripheral PbPb collisions – excellent signal to background
 very good understanding of line shape
 (probes nuclear gluon shadowing, not discussed here)

ALICE EPJ C73 arXiv:1305.1467

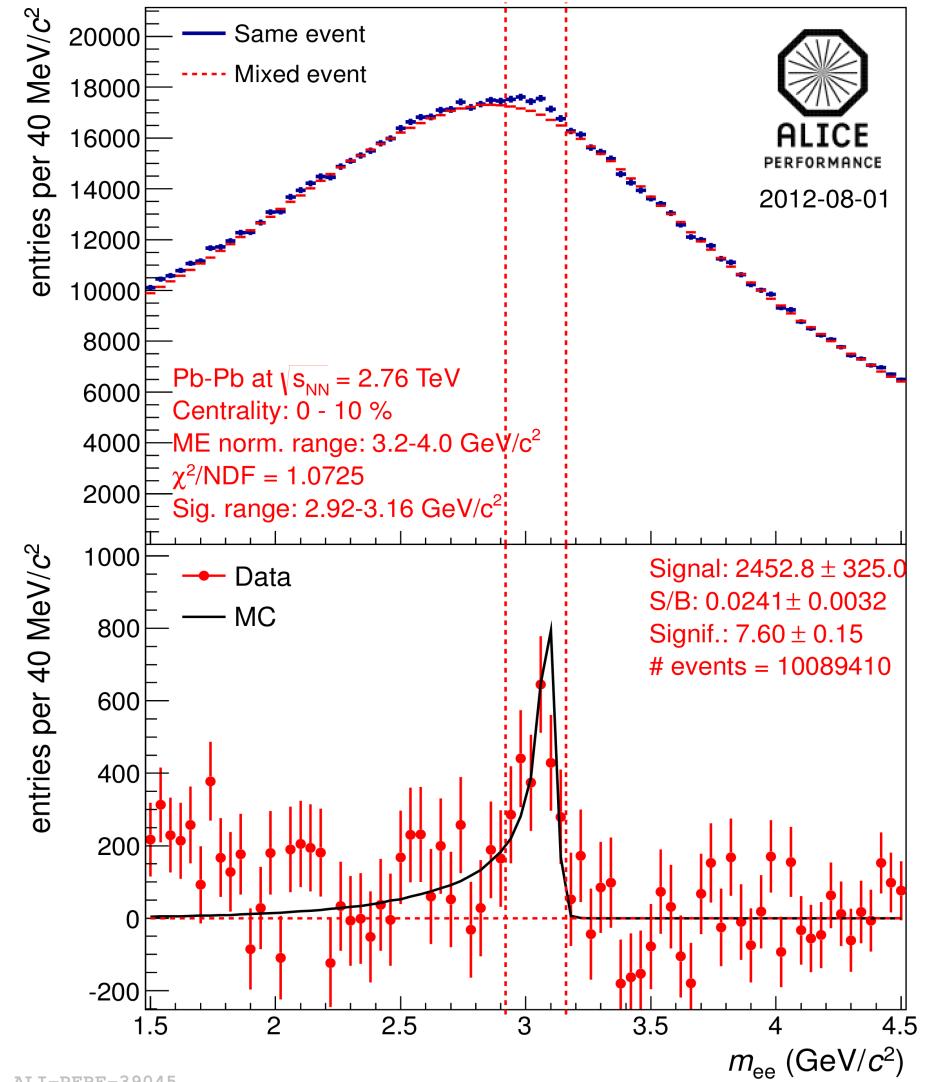


reconstruction of J/psi for central nuclear collisions



ALI-PUB-42637

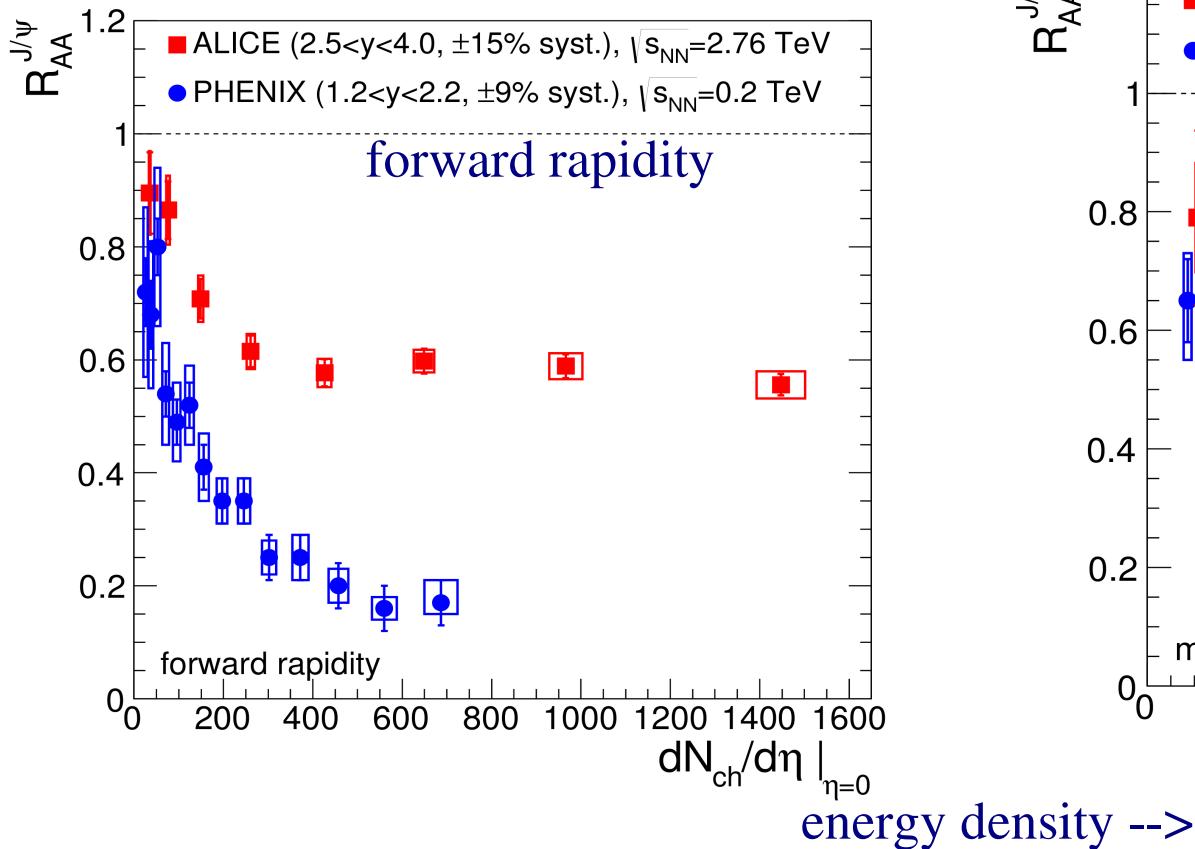
most challenging: central PbPb collisions
in spite of formidable combinatorial background
(true electrons, not from J/ψ decay but e.g. D- or B-mesons) resonance well visible



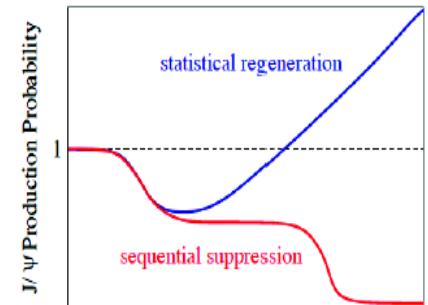
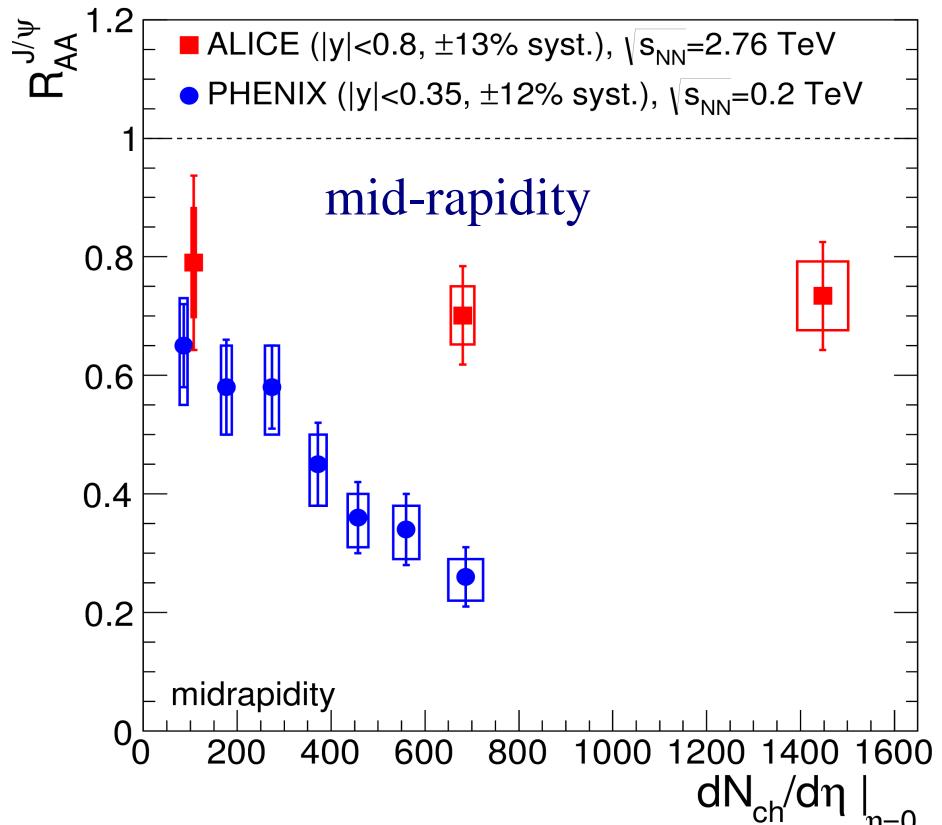
ALI-PERF-39045

J/psi production in PbPb collisions: LHC relative to RHIC

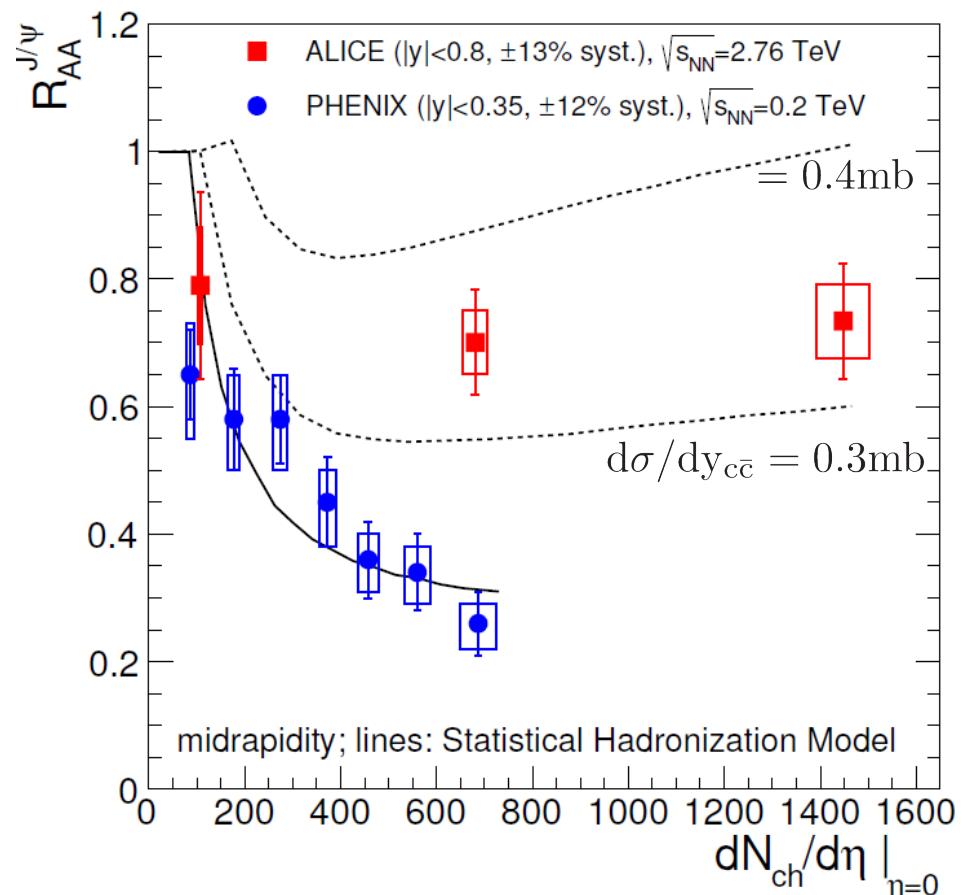
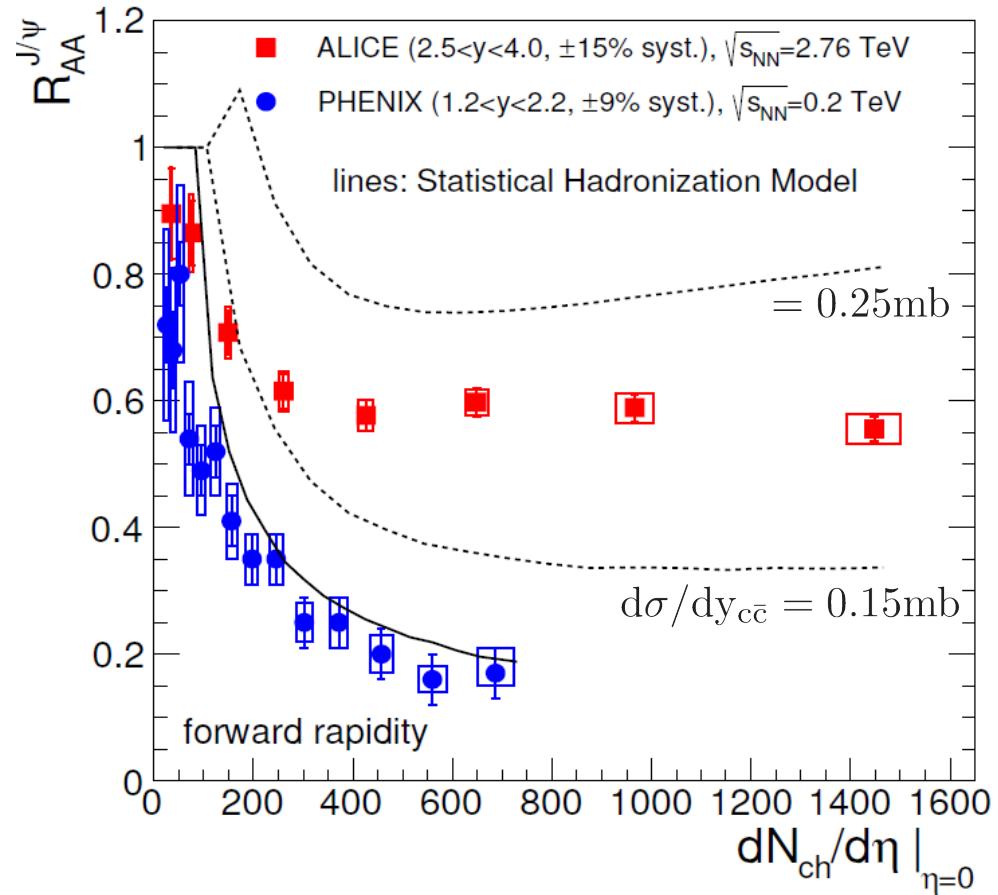
$$R_{AA}(p_T) = \frac{(1/N_{\text{evt}}^{AA}) d^2N_{\text{ch}}^{AA}/d\eta dp_T}{\langle N_{\text{coll}} \rangle (1/N_{\text{evt}}^{PP}) d^2N_{\text{ch}}^{PP}/d\eta dp_T}$$



melting scenario not observed
rather: **enhancement with increasing energy density!**
(from RHIC to LHC and from forward to mid-rapidity)



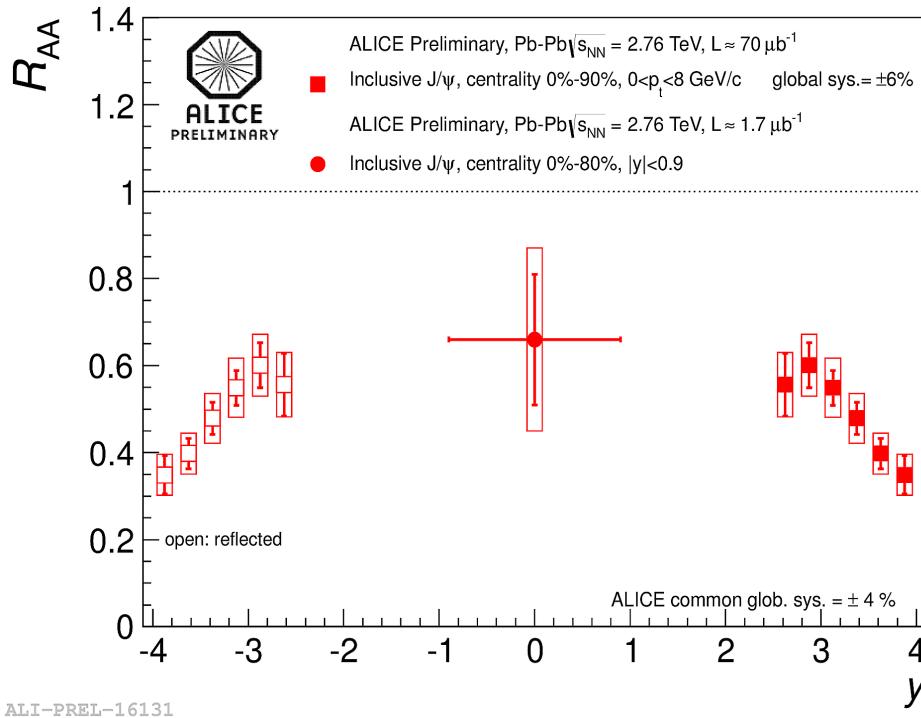
J/psi and statistical hadronization



production in PbPb collisions at LHC consistent with deconfinement and subsequent statistical hadronization within present uncertainties

transport models also in line with R_{AA} but different open charm cross section used
 (0.5-0.75mb TAMU and 0.65-0.8 mb Tsinghua vs. 0.3-0.4 mb SHM) more below
 — main uncertainties for models: open charm cross section, shadowing in Pb

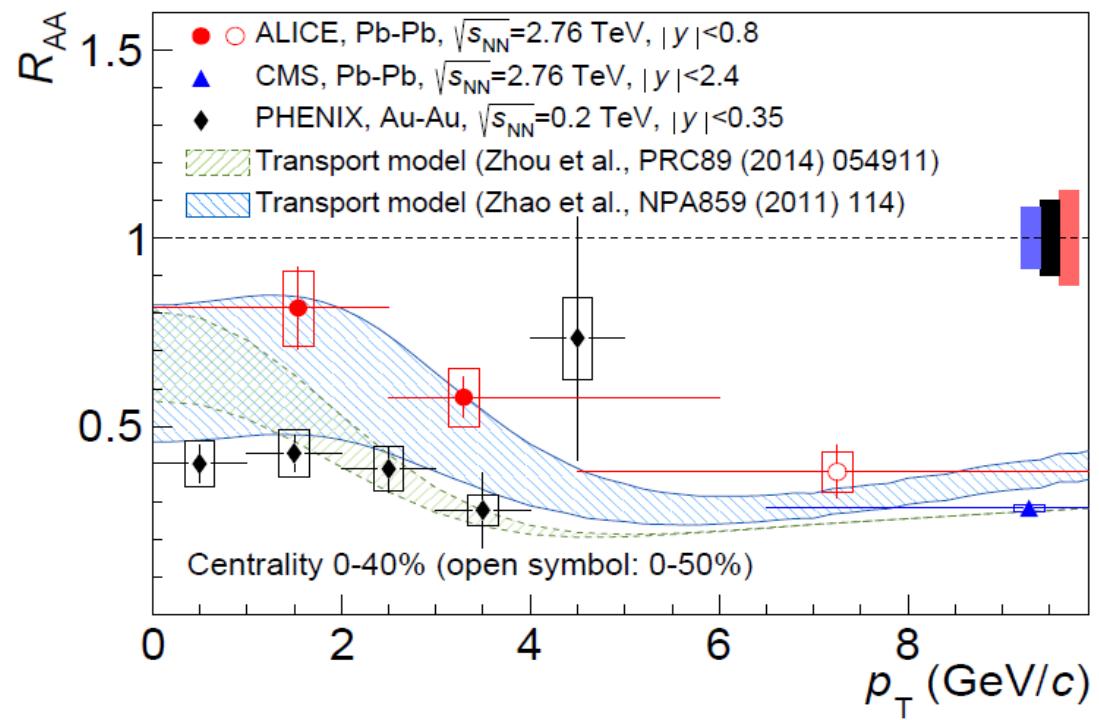
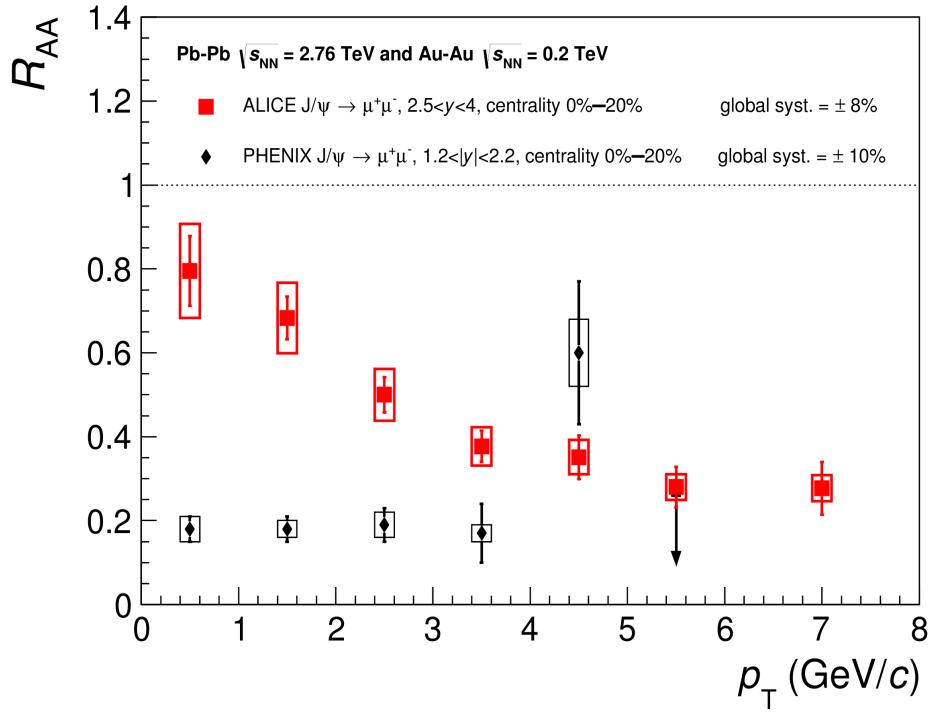
Rapidity dependence of R_{AA}



yield in PbPb peaks at mid- y
where energy density is largest

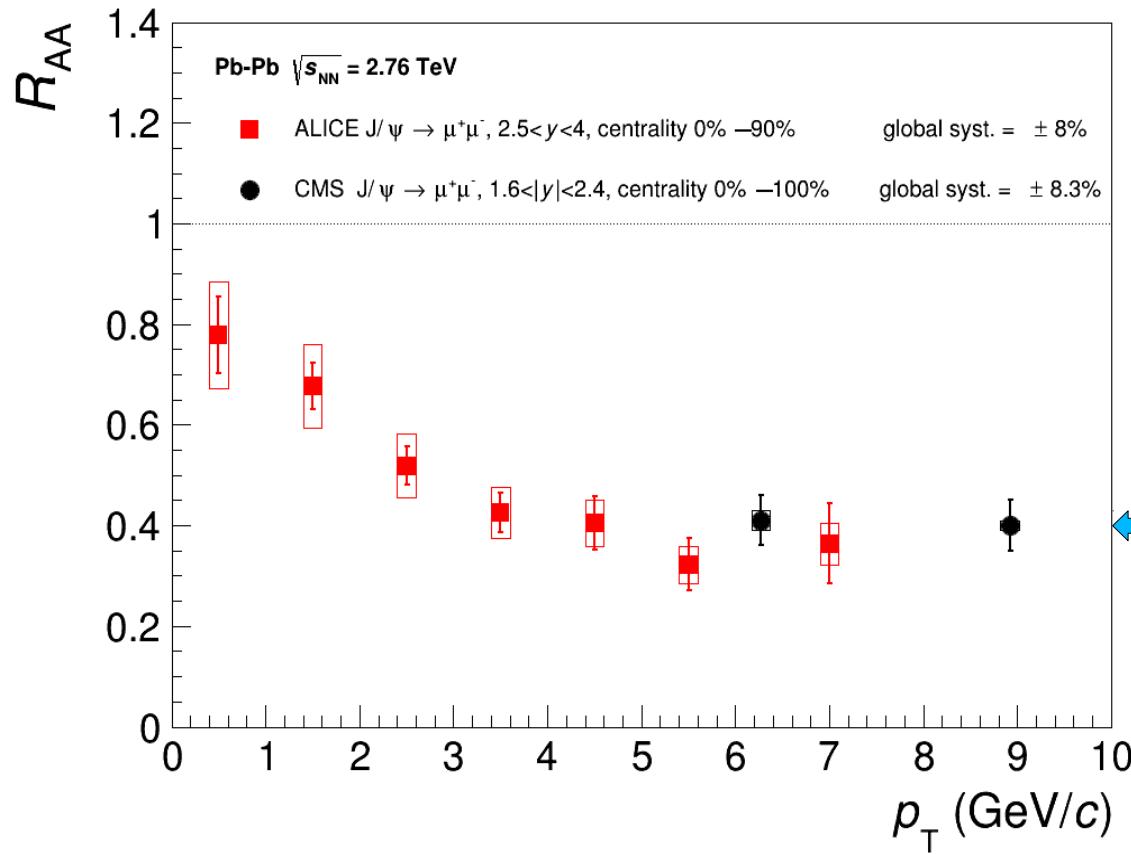
for statistical hadronization J/ψ yield proportional to N_c^2 - higher yield at mid-rapidity predicted in line with observation

p_t dependence of R_{AA} supports dominance of new production mechanism at LHC at small p_t



p_t dependence at LHC opposite to RHIC
supports argument: thermalized deconfined charm quarks hadronize into J/ψ

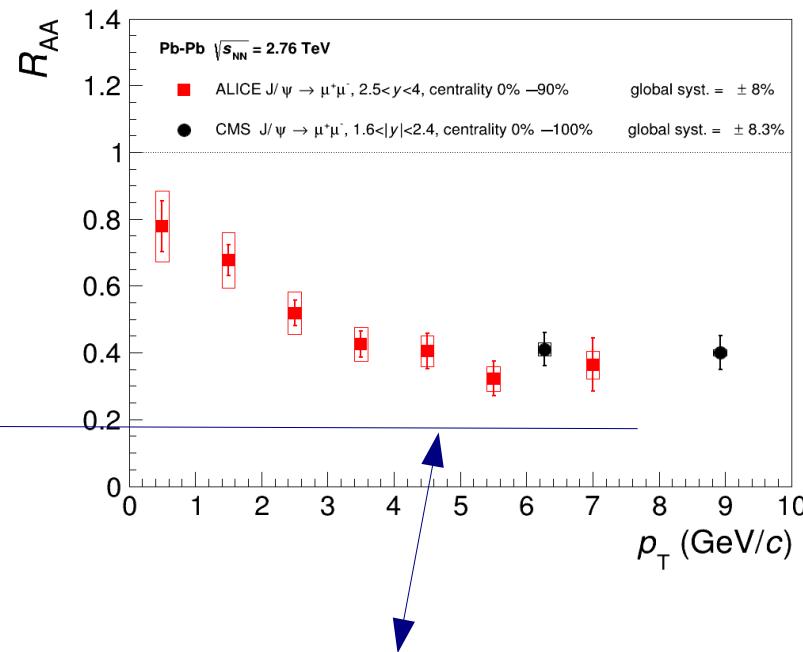
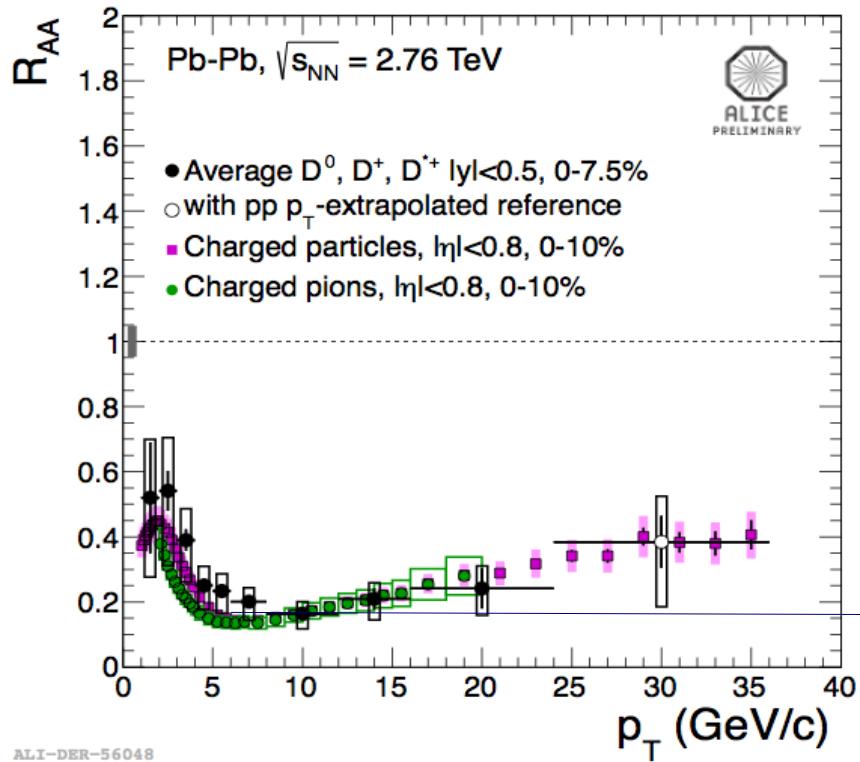
p_t dependence of R_{AA}



what effects to expect?

- statistical hadronization in p_t range where charm quarks are reasonably thermal
- modification of spectrum relative to pp due to radial flow
- suppression in R_{AA} due to charm quark energy loss (see D mesons)

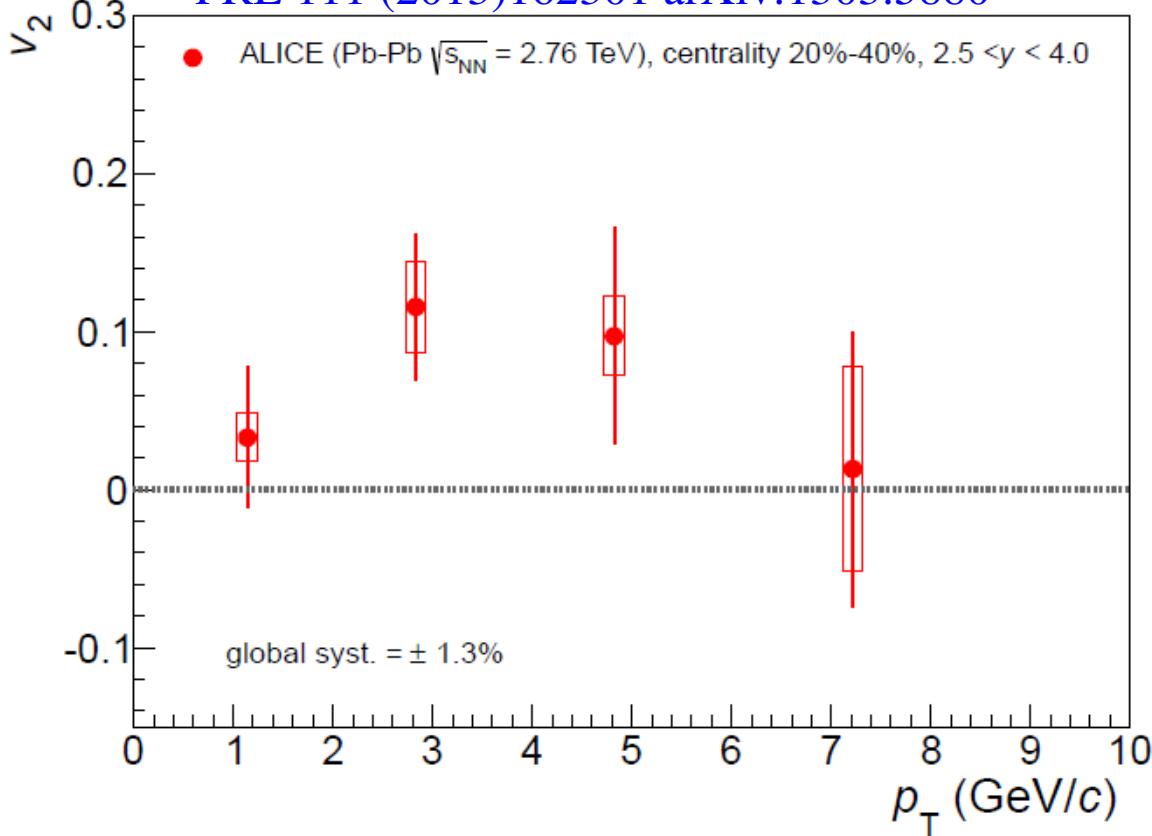
p_t dependence of R_{AA}



is high p_t part indicative of the same charm quark energy loss seen for D's
out to what p_t is statistical hadronization/regeneration relevant?

elliptic flow of J/psi vs p_t

PRL 111 (2013)162301 arXiv:1303.5880

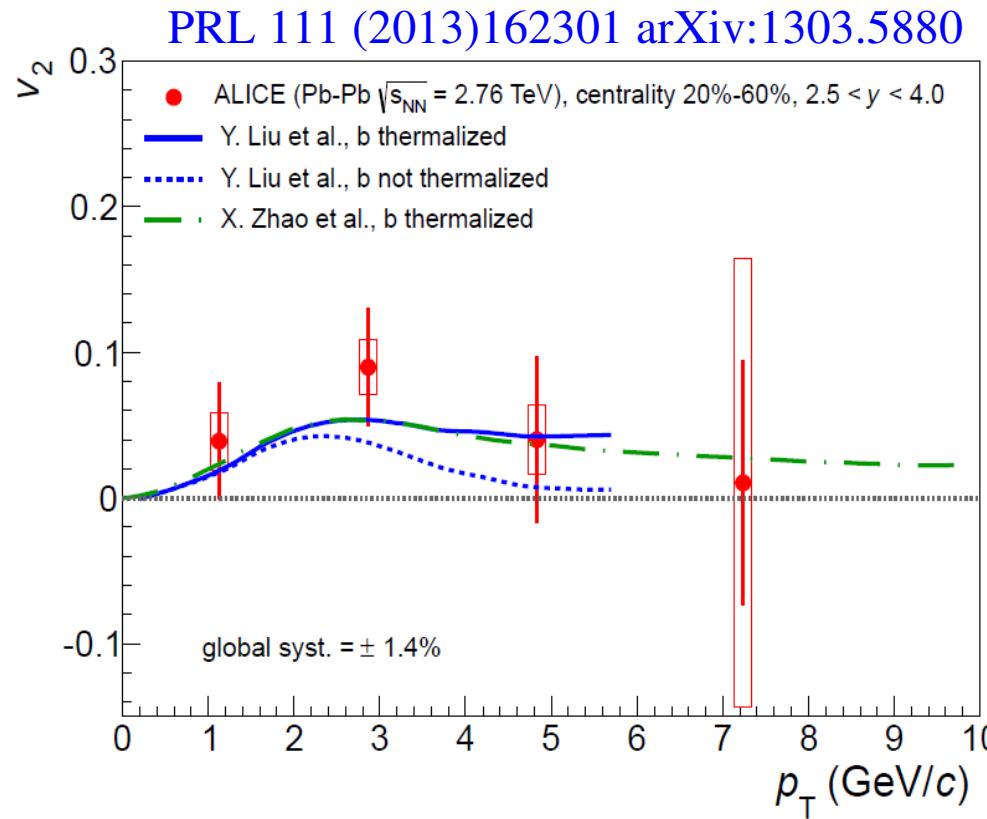


charm quarks thermalized in the QGP should exhibit the elliptic flow generated in this phase

- expect build-up with p_t as observed for π , p, K, Λ , ... and vanishing signal for high p_t region where J/ψ not from hadronization of thermalized quarks

first observation of $J/\psi v_2$
in line with expectation from statistical
hadronization

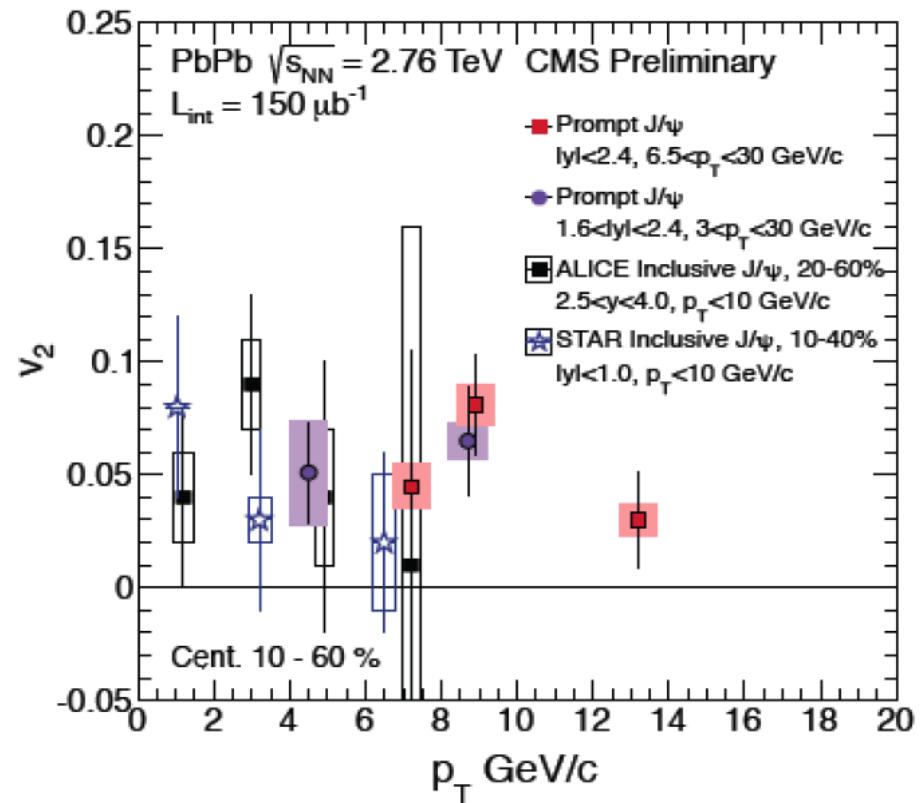
J/psi flow compared to models including (re-) generation



v_2 of J/ψ consistent with hydrodynamic flow of charm quarks in QGP
and statistical (re-)generation

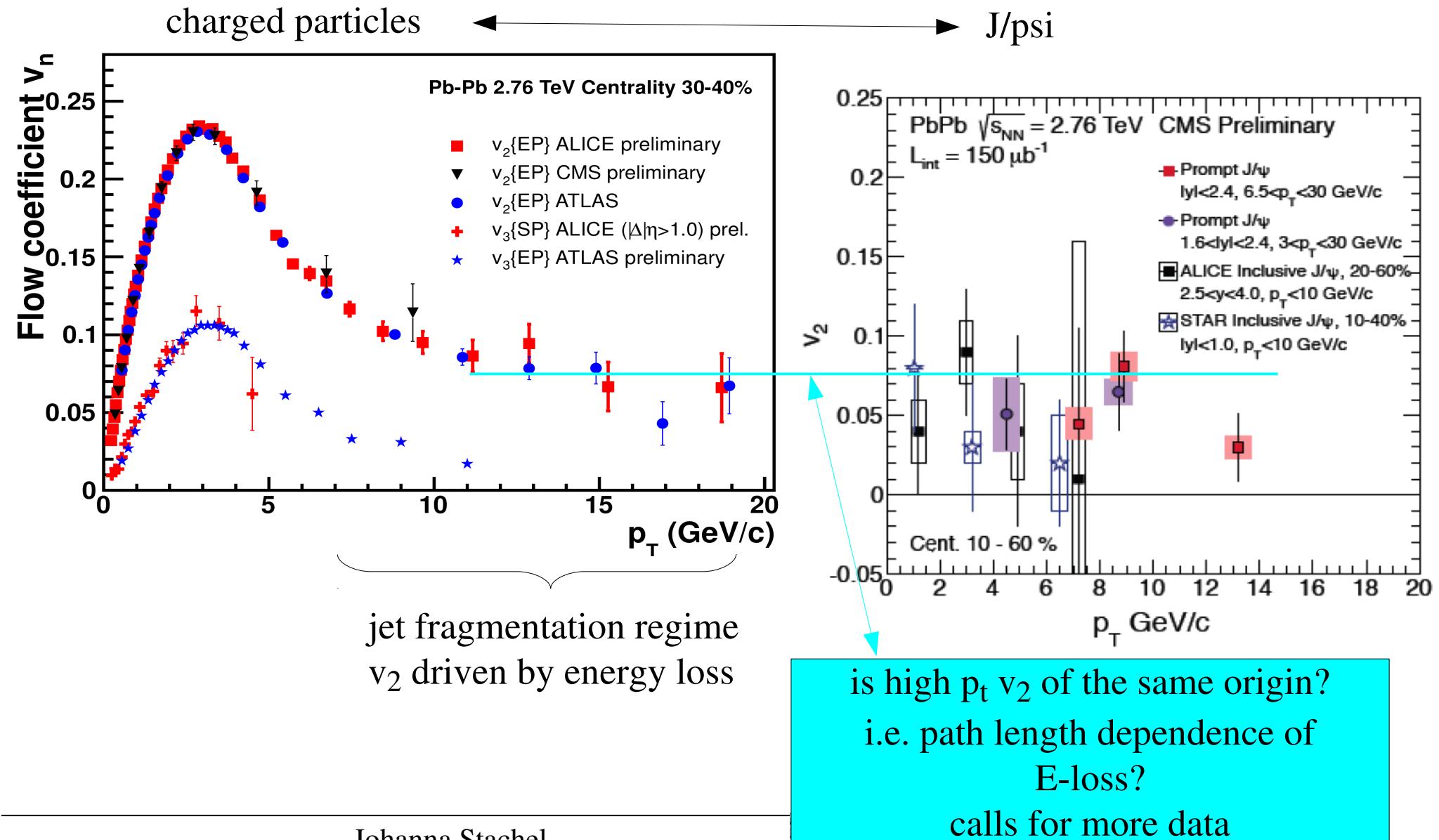
but:

CMS observes similar v_2 at higher p_T

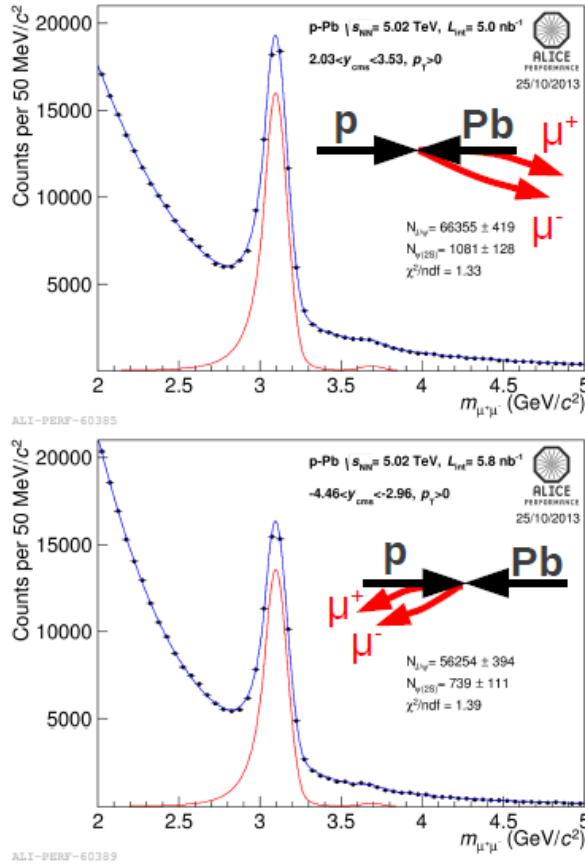


this calls for
more and better data

J/psi flow compared to models including (re-) generation



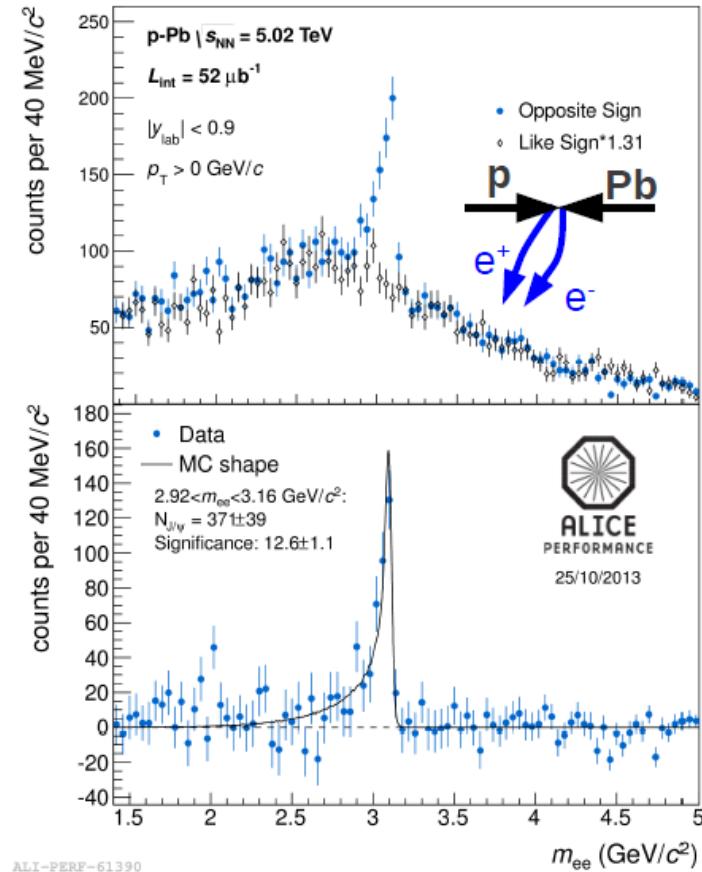
modification of charm production in nuclei: pA collisions



Dimuons: dedicated trigger

$L_{int} = 5.0 \text{ nb}^{-1}$ (forward)

$L_{int} = 5.8 \text{ nb}^{-1}$ (backward)

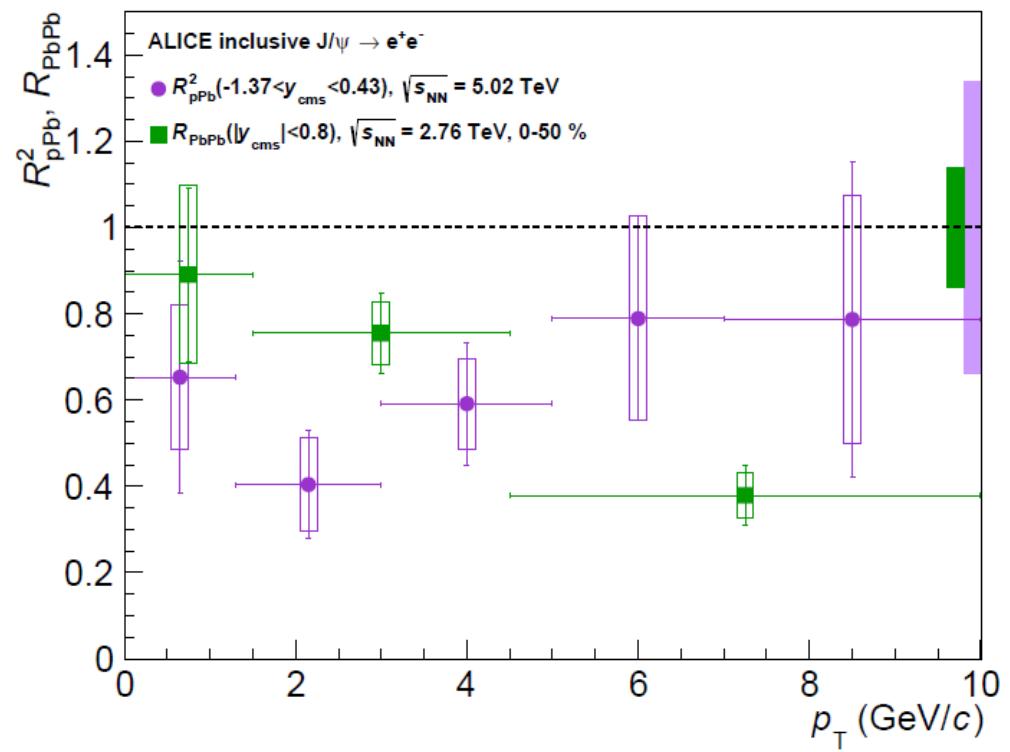
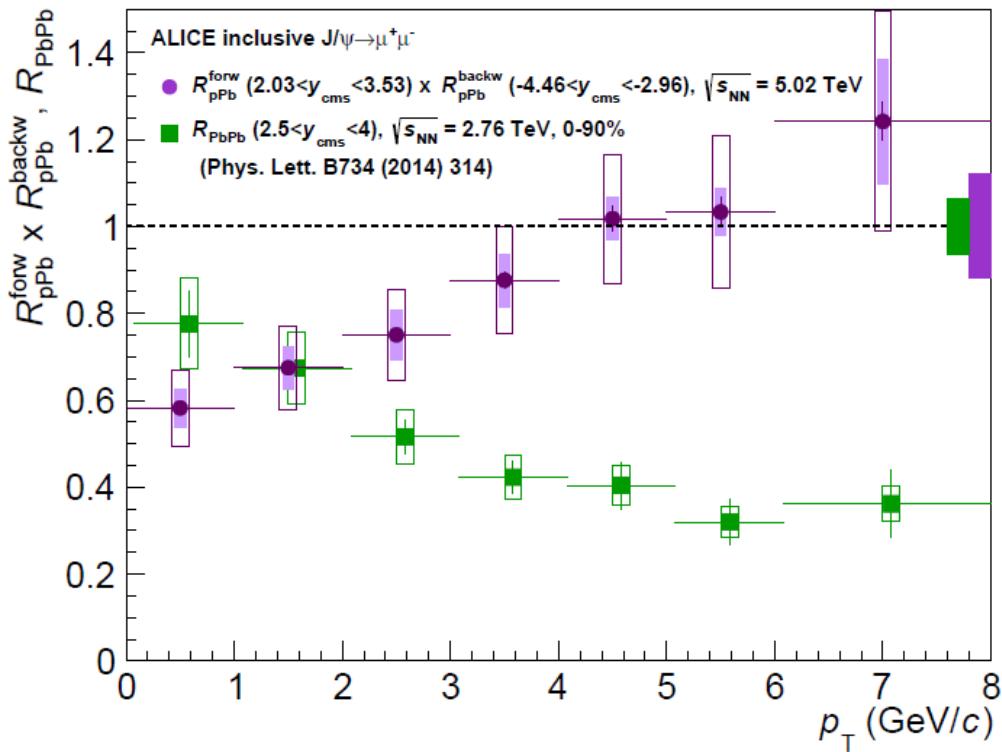


Dielectrons: Minimum Bias

$L_{int} = 52 \mu\text{b}^{-1}$

J/psi vs p_t in PbPb collisions relative to pPb collisions

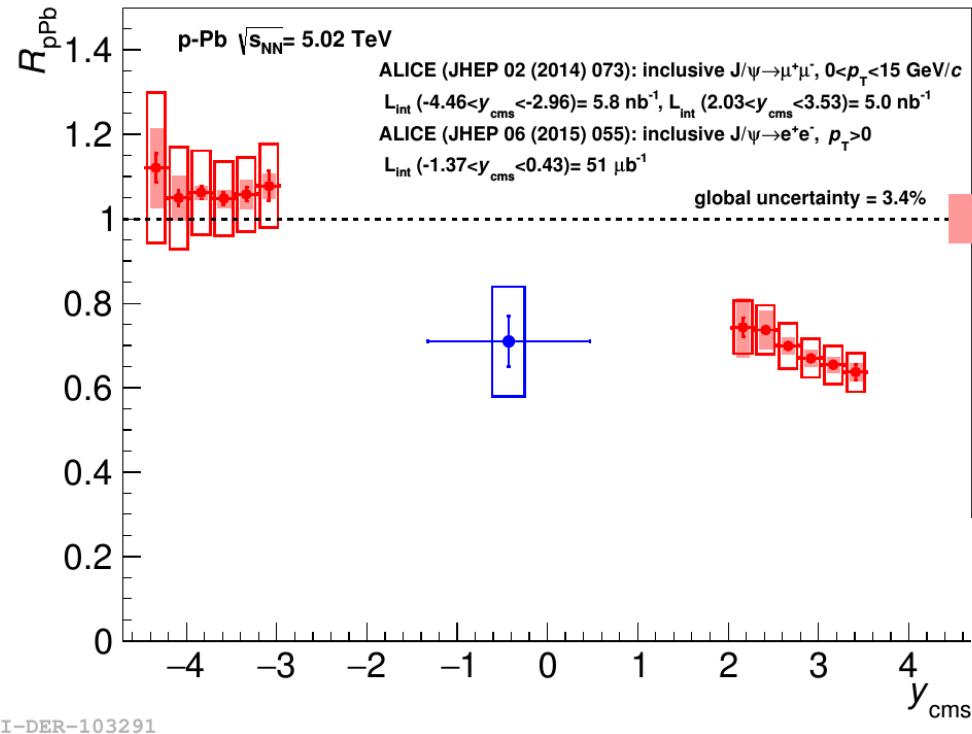
JHEP 1506 (2015) 055, arXiv:1503.07179



at low p_t yield in nuclear collisions above pPb collisions

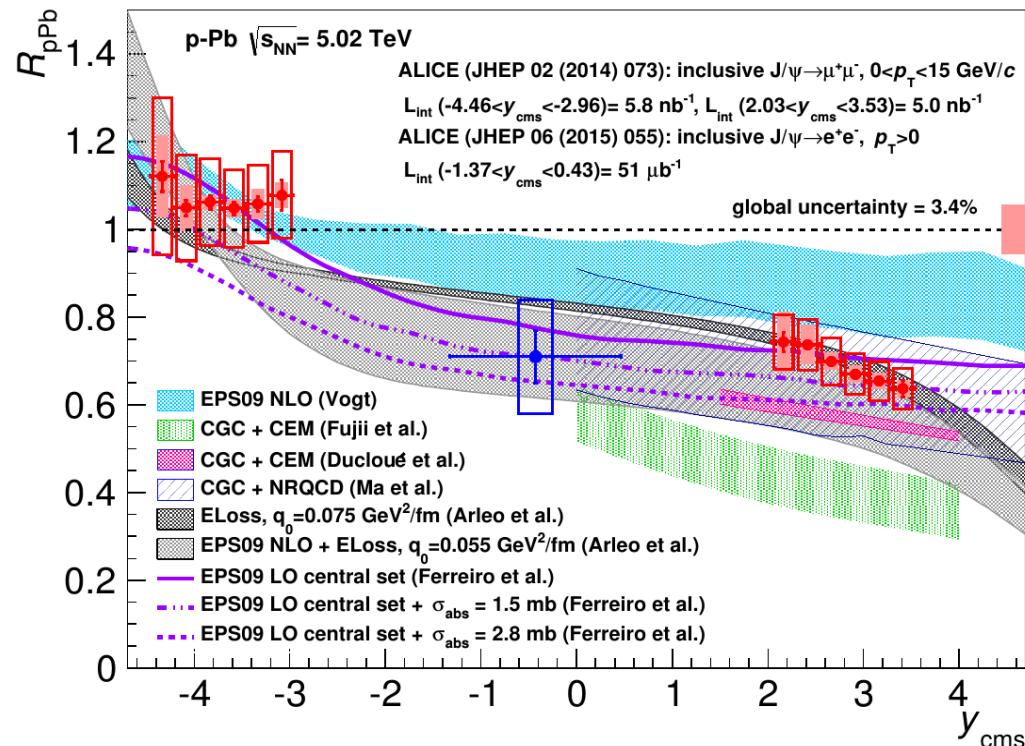
J/psi production **enhanced** in nuclear collisions **over mere shadowing effect**

J/psi rapidity distribution in pPb compared to pp



use these data to extract relevant shadowing for J/psi production in PbPb:
for mid-y suppression by 0.56 ± 0.20
(all data + consult R.Vogt)
for $y = 2.5\text{-}4.0$ “ 0.71 ± 0.10
(forward/backward data + consult R.Vogt)

ALICE forward/backward
arXiv:1308.6726 JHEP 1402 (2014) 073
good agreement with LHCb
arXiv:1308.6729 JHEP 1402 (2014) 072
ALICE mid-y
arXiv:1503.07179 JHEP 1506 (2015) 055



Back to ccbar cross section

crucial input for both statistical hadronization model and transport models for destruction and regeneration of charmonia

sofar, no measurement of the cross section for PbPb

proxy: take pp cross section at 7 TeV and scale to 2.76 TeV using FONLL \sqrt{s} dependence

LHCb: $y=2.0\text{-}4.5$ and 7 TeV $d\sigma(cc\bar{c})/dy = 0.568 \pm 0.054 \text{ mb}$

extrapolate to 2.76 TeV and $y=2.4\text{-}4.0$ “ = $0.290 \pm 0.028 \text{ mb}$

apply shadowing ($x 0.71 \pm 0.10$) “ = $0.206 \pm 0.035 \text{ mb}$

baseline for PbPb

ALICE: use master thesis Ch. Moehler, D-measurement down to $pt=0$

$|y| \leq 0.5$ and 7 TeV $d\sigma(cc\bar{c})/dy = 0.879 \pm 0.135 \text{ mb}$

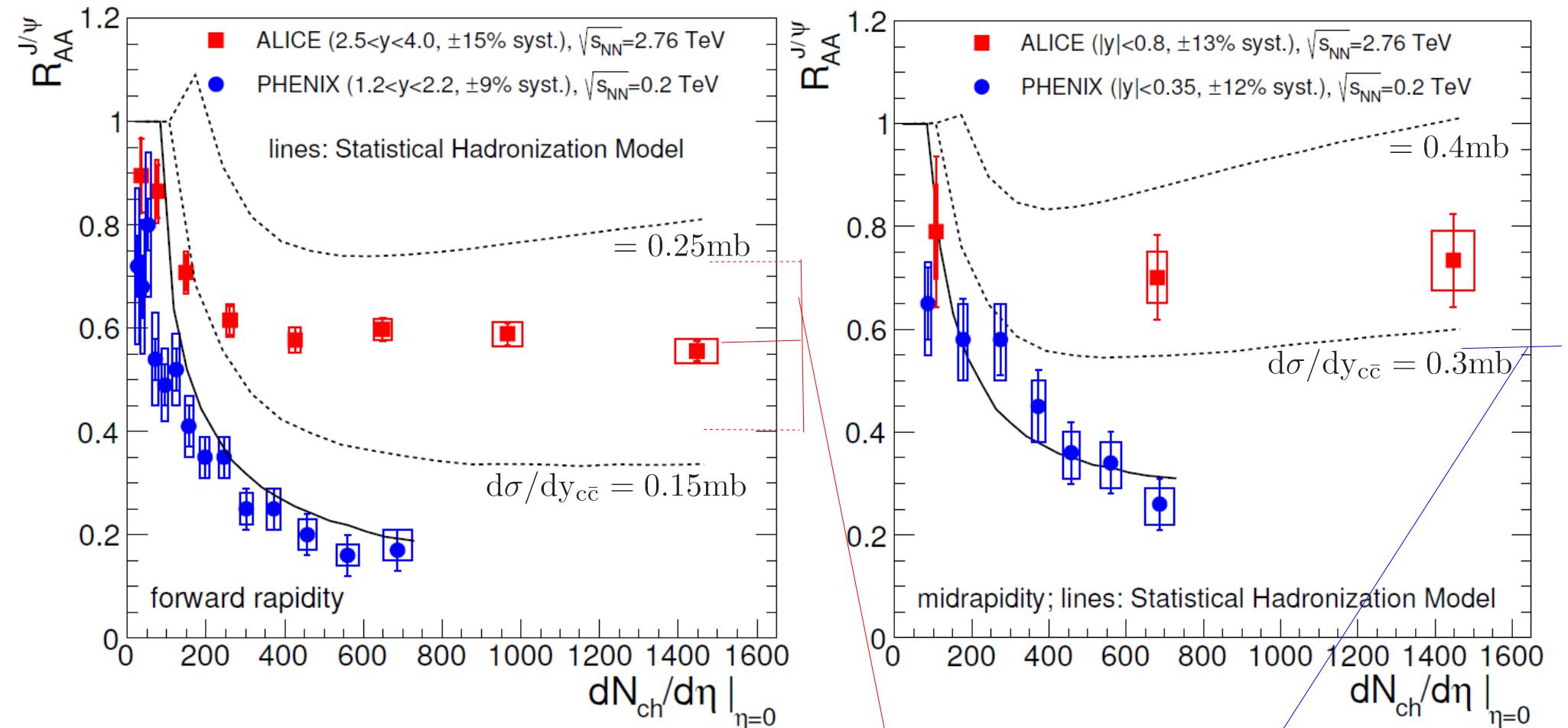
extrapolate to 2.76 TeV “ = $0.521 \pm 0.080 \text{ mb}$

apply shadowing ($x 0.56 \pm 0.20$) “ = $0.292 \pm 0.114 \text{ mb}$

baseline for PbPb

comment: published ALICE 18% larger with larger extrapolation error – consistent
use LHCb and extrapolate to mid-y 15% lower - consistent within error

J/psi and statistical hadronization



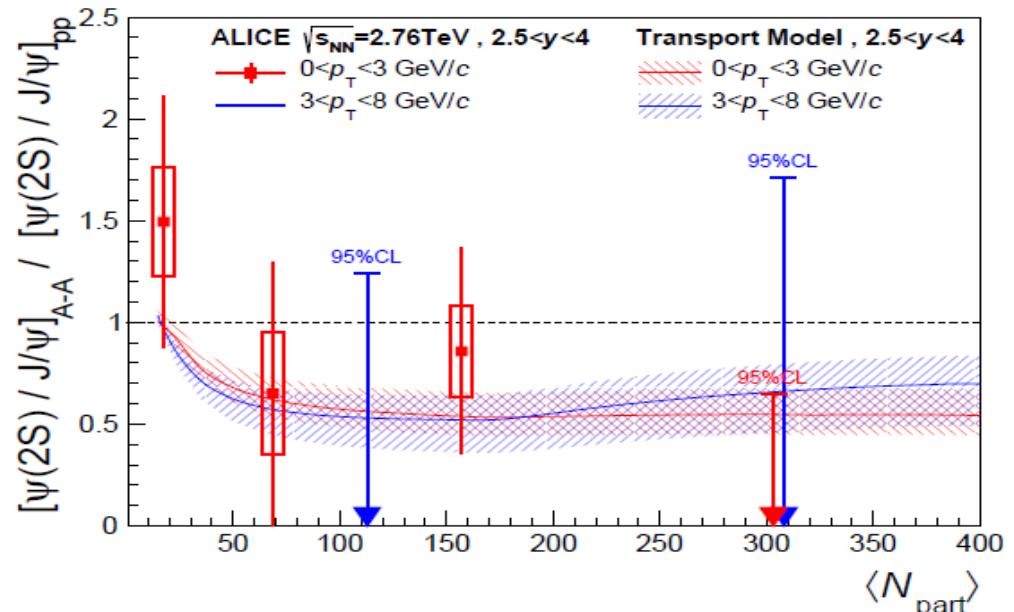
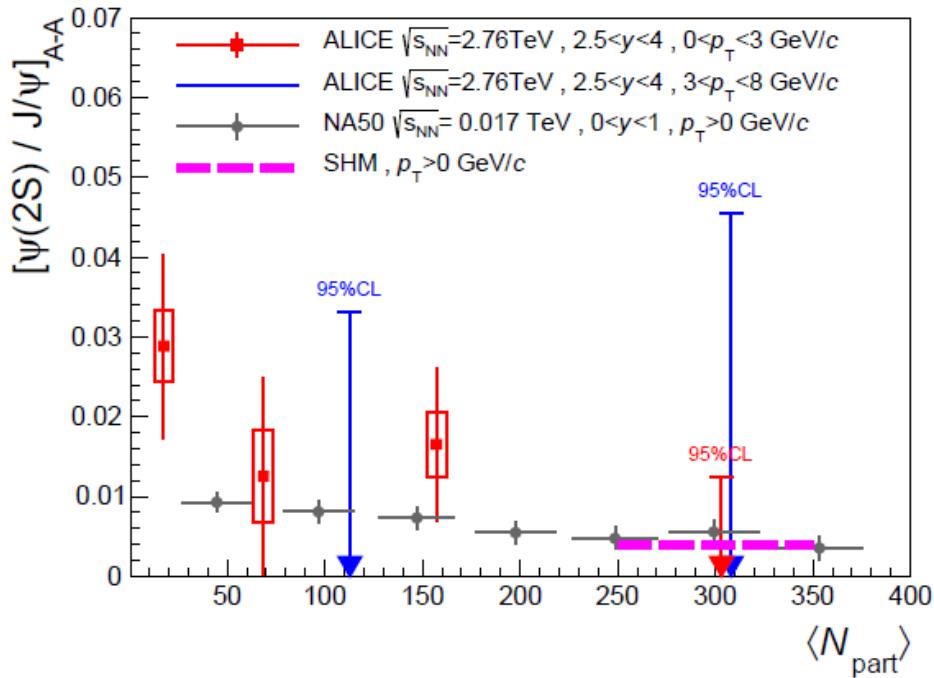
- main uncertainties for models: open charm cross section, shadowing in Pb

$$\begin{aligned}
 y = 2.4-4.0 \quad & dsigma(cc\bar{c})/dy = 0.206 \pm 0.035 \text{ mb} \\
 \text{mid-}y \quad & " \quad \quad \quad = 0.292 \pm 0.114 \text{ mb}
 \end{aligned}$$

transport models should use same cross section!

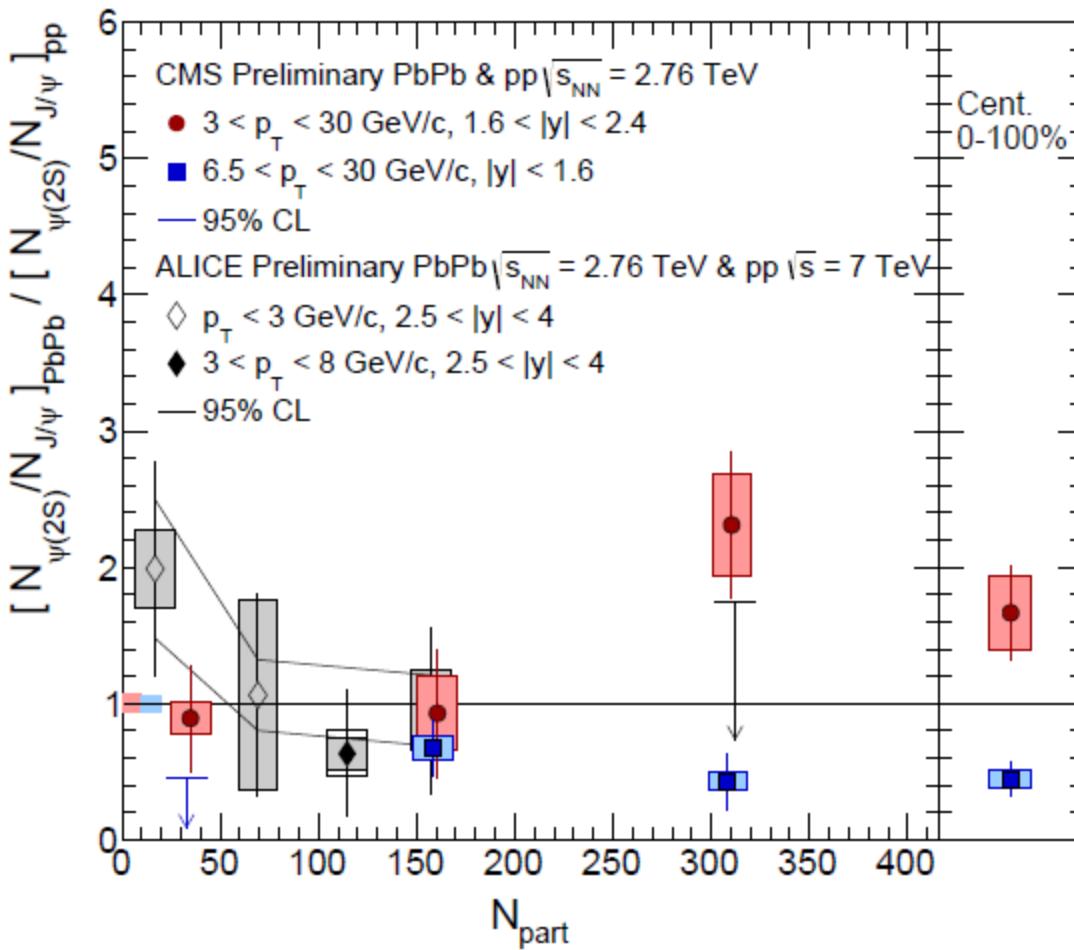
psi' to J/psi at LHC

arXiv: 1506.08804



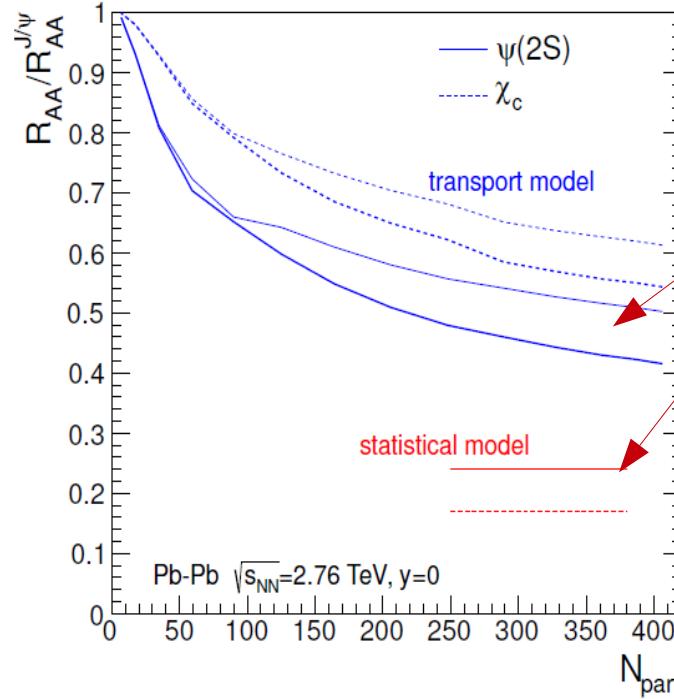
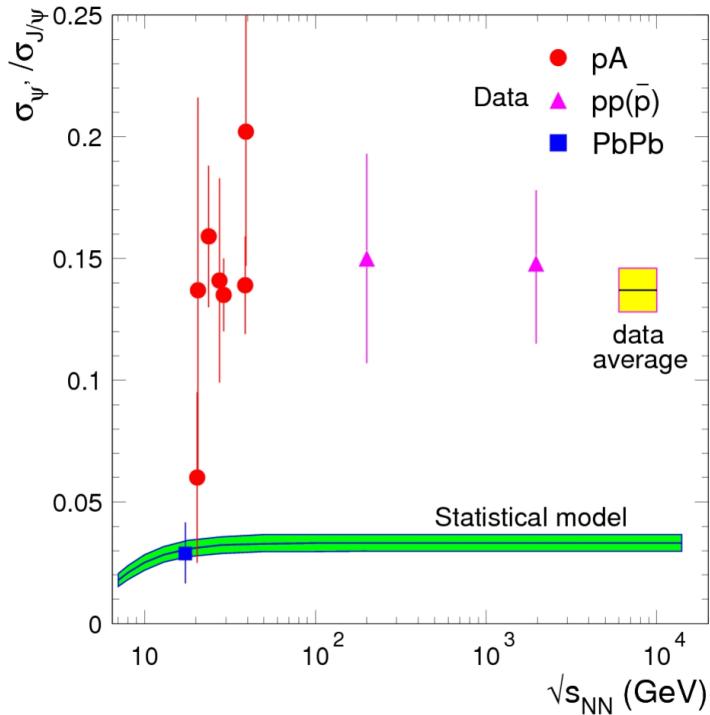
- experimental errors still significant
- within errors consistent with low value in statistical model due to suppression with Boltzmann factor
- also consistent with larger values resulting from transport models

ψ' to J/ ψ at LHC - not yet conclusive



- errors of data still large
- are we seeing a peculiar p_T dependence? If so, could we see effect of collective flow of charm quarks before hadronization?

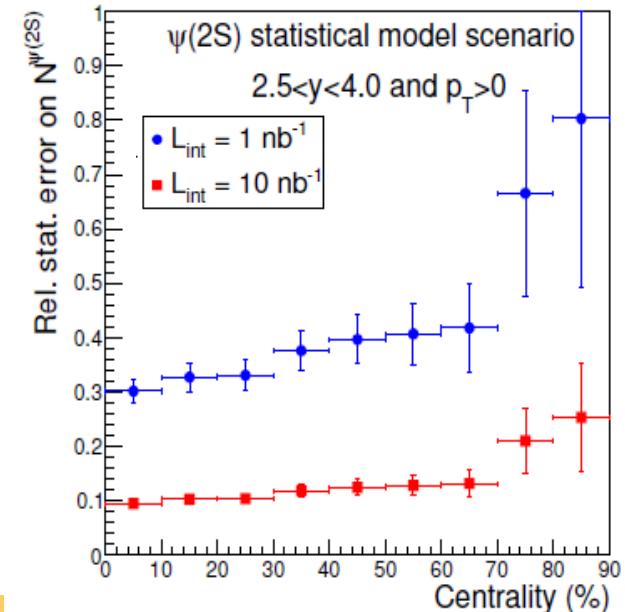
excited charmonia crucial to distinguish between models



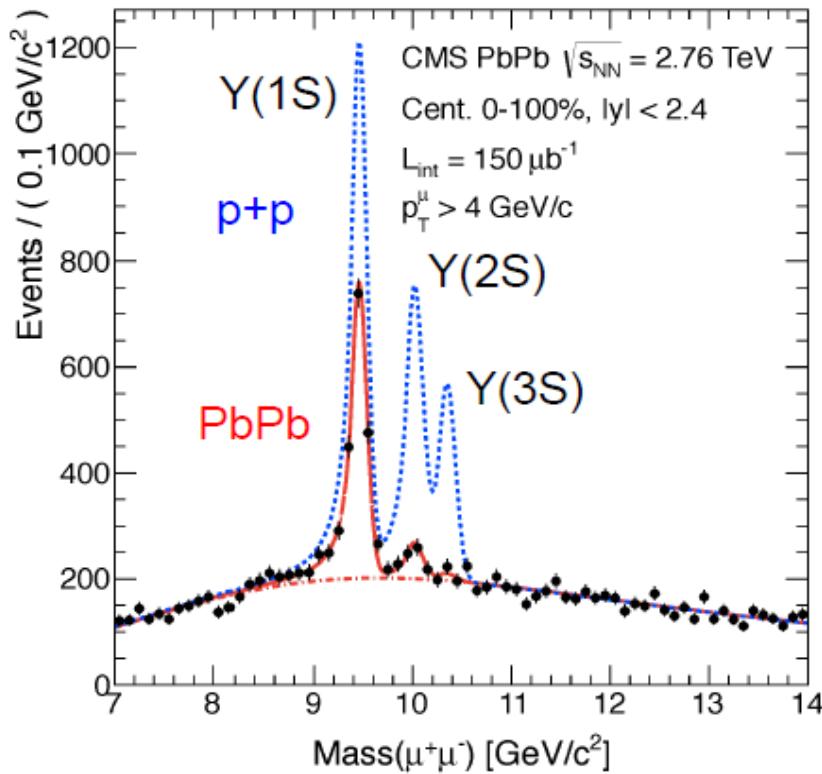
in fact here one can distinguish between the transport models that form charmonia already in QGP and statistical hadronization at phase boundary!

for statistical hadronization need to see suppression by Boltzmann factor
 χ_c even bigger difference

expected ALICE performance →
 muon arm run2 and run3



suppression of Upsilon states



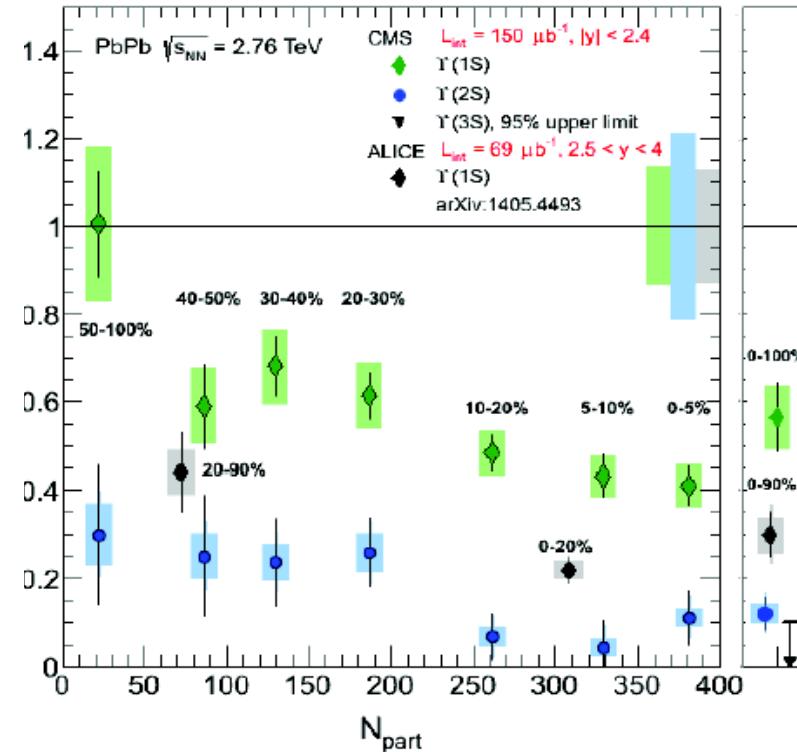
$$R_{AA}(\Upsilon(1S)) = 0.56 \pm 0.08 \pm 0.07$$

$$R_{AA}(\Upsilon(2S)) = 0.12 \pm 0.04 \pm 0.02$$

$$R_{AA}(\Upsilon(3S)) < 0.10 @ 95\% \text{ CL}$$

+ $R_{AA}(\Upsilon(1S)) = 0.30 \pm 0.05 \pm 0.04$
(at forward rapidity)

CMS, PRL109 (2012) 222301
ALICE, PLB738 (2014) 361

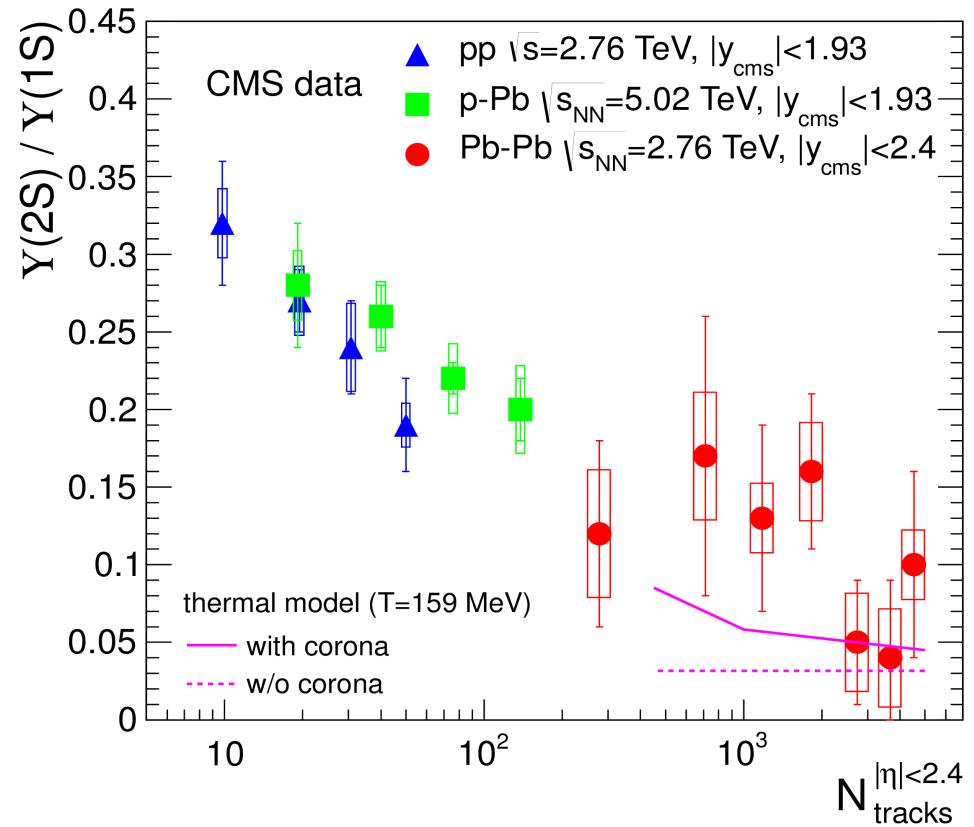
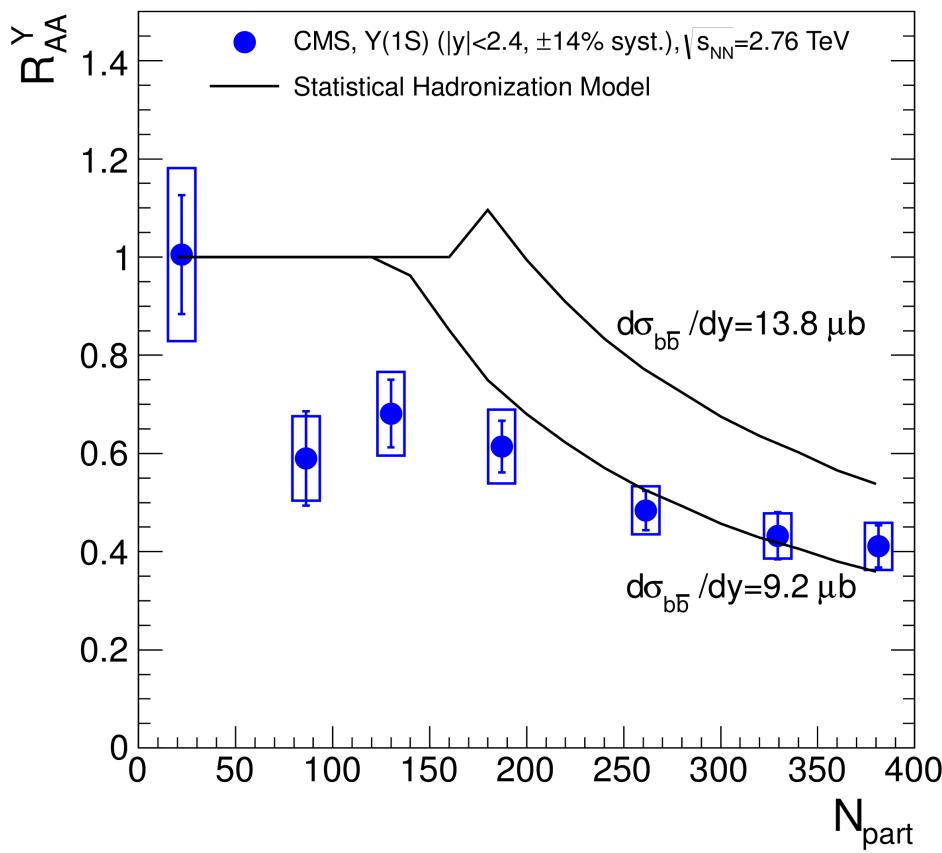


not consistent with just excited state suppression (LHCb data: only 25 % feed-down in pp at LHC)

another puzzle: radius of Upsilon $\psi(2S)$ similar to radius J/ψ but at mid-y $R_{AA} = 0.12$ vs 0.70

the Upsilon could also come from statistical hadronization

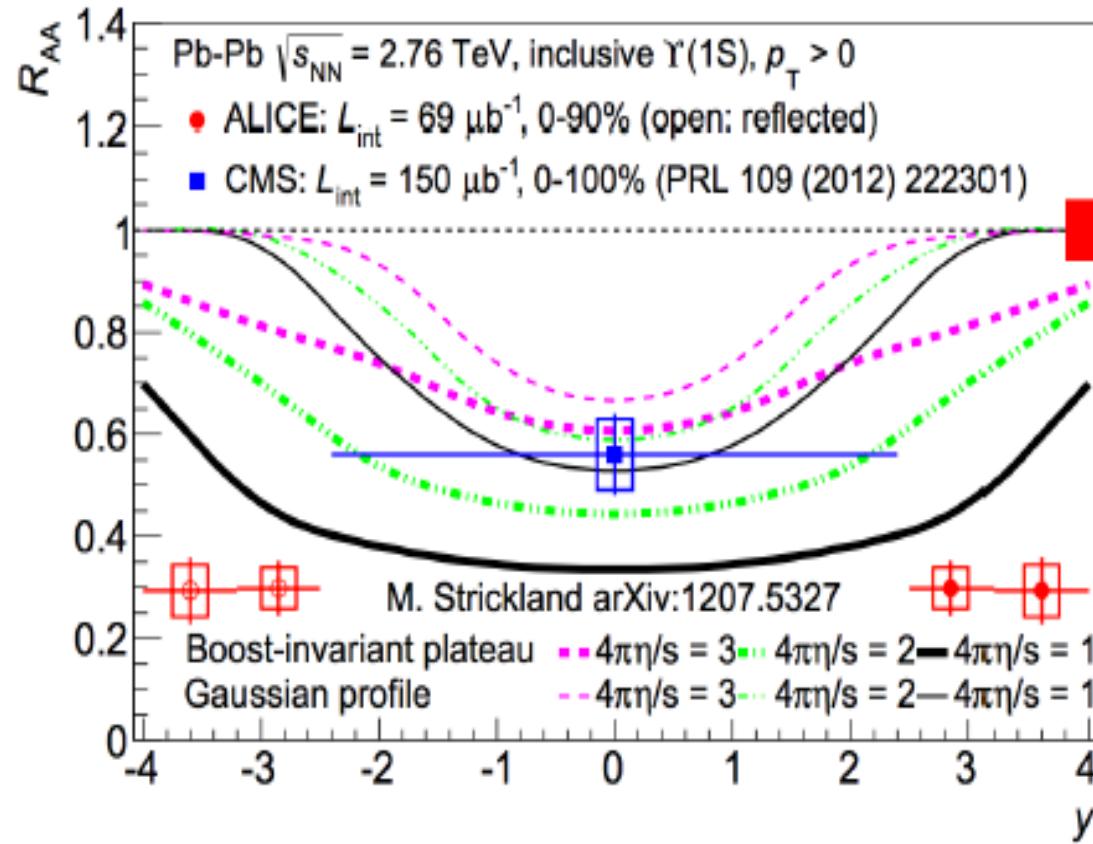
SHM/thermal model: Andronic et al.



in this picture, the entire Upsilon family is formed at hadronization
 but: need to know first – do b-quark thermalize at all? spectra of B
 - total b-cross section in PbPb

Upsilon R_{AA}rapidity dependence

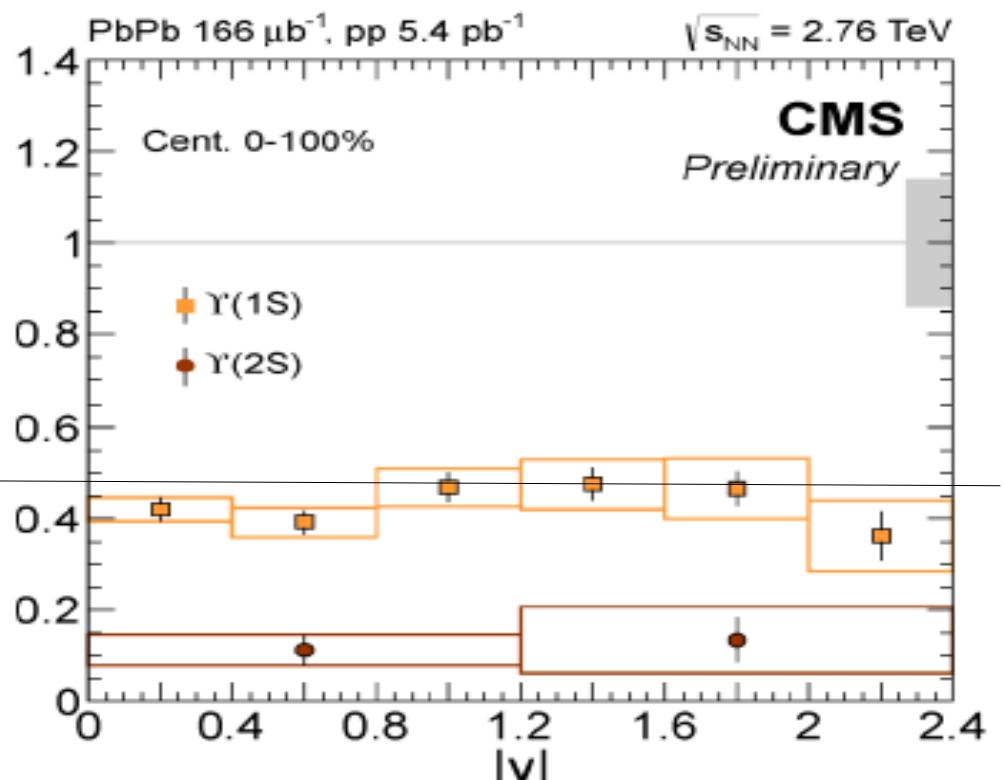
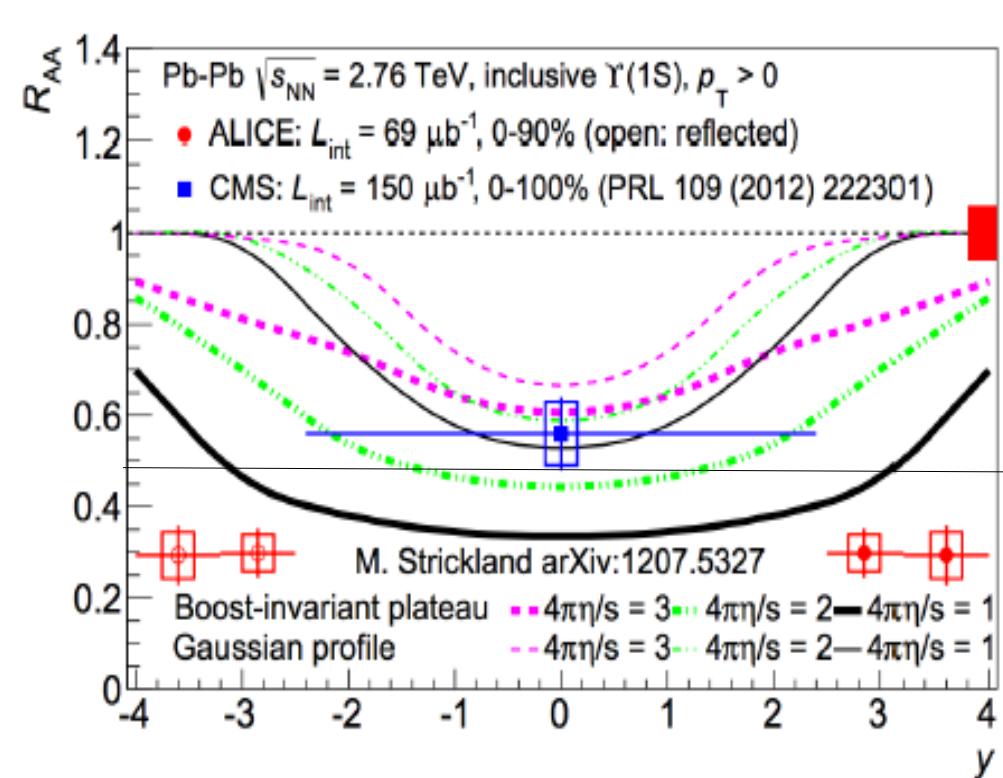
arXiv:1503:03427



R_{AA} peaked at mid- y like for J/psi difficult for models with Debye screening or gluon dissociation only – natural for generation from deconfined b-quarks via statistical hadronization

Upsilon R_{AA}rapidity dependence

CMS 20 times more statistics in pp M. Jo, QM2015, CMS-HIN-15-001



R_{AA} still peaked at mid-y like for J/psi

First determination of Debye mass from data

J/psi formation via statistical hadronization at T_c implies
experimental determination of Debye length (mass) and temperature
 $\lambda_D < 0.4$ fm at $T = 156$ MeV or $\omega_D/T > 3.3$
can compare to theory:

quite ok

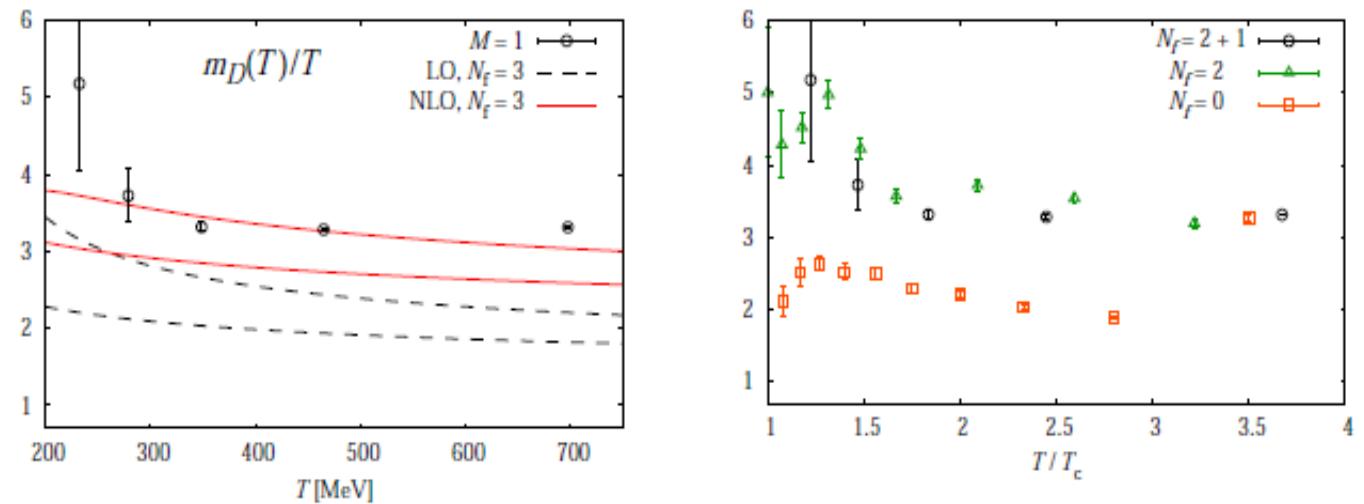


Fig. 6. (Left) The Debye screening mass on the lattice in the color-singlet channel together with that calculated in the leading-order (LO) and next-to-leading-order (NLO) perturbation theory shown by dashed-black and solid-red lines, respectively. The bottom (top) line expresses a result at $\mu = \pi T$ ($3\pi T$), where μ is the renormalization point. (Right) Flavor dependence of the Debye screening masses. We assume the pseudo-critical temperature for 2 + 1-flavor QCD as $T_c \sim 190$ MeV.

arXiv:1112.2756 WHOT-QCD Coll.

summary

lots of new experimental data

clear indication of new production mechanism for charmonia at LHC
supported by yields, spectra, rapidity distribution, v_2
data consistent with statistical hadronization model and transport
model approaches

limitation in interpretation:

precision measurement of open charm cross section in PbPb
statistics of charmonium observables

bottomonium data not in line with simple screening picture
statistical hadronization as well? Does beauty thermalize in QGP?

expect significant progress from run2 and run3 LHC data from all
experiments

backup

Quarkonium Properties and Debye Screening

state	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ'_b	Υ''
mass [GeV]	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE [GeV]	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM [GeV]	0.02	-0.03	0.03	0.06	-0.06	-0.06	-0.08	-0.07
radius [fm]	0.25	0.36	0.45	0.14	0.22	0.28	0.34	0.39

table from H. Satz, J. Phys. G32 (2006) R25

In the QGP, the screening radius $r_{\text{Debye}}(T)$ decreases with increasing T . If $r_{\text{Debye}}(T) < r_{\text{charmonium}}$ the system becomes unbound \rightarrow suppression compared to charmonium production without QGP. The screening radius can be computed using potential models or solving QCD on the lattice.

extension of statistical model to include charmed hadrons

- assume: all charm quarks are produced in initial hard scattering; number not changed in QGP
- hadronization at T_c following grand canonical statistical model used for hadrons with light valence quarks (A. Andronic, P. Braun-Munzinger, J.S. or J. Cleymans, K. Redlich or F. Becattini)
number of charm quarks fixed by a charm-balance equation containing fugacity g_c

$$N_{c\bar{c}}^{direct} = \frac{1}{2} g_c V \left(\sum_i n_{D_i}^{therm} + n_{\Lambda_i}^{therm} \right) + g_c^2 V \left(\sum_i n_{\psi_i}^{therm} \right) + \dots$$

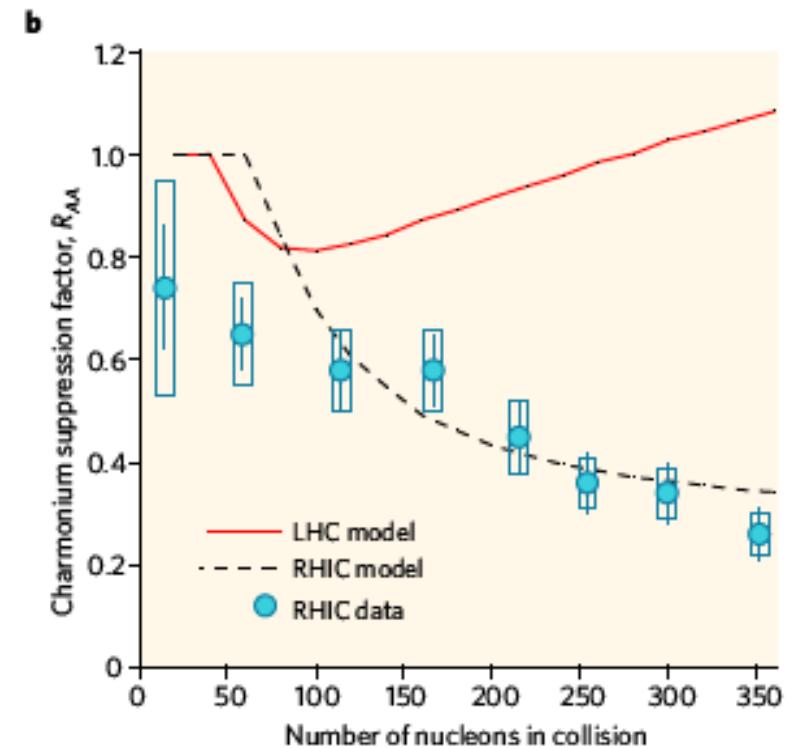
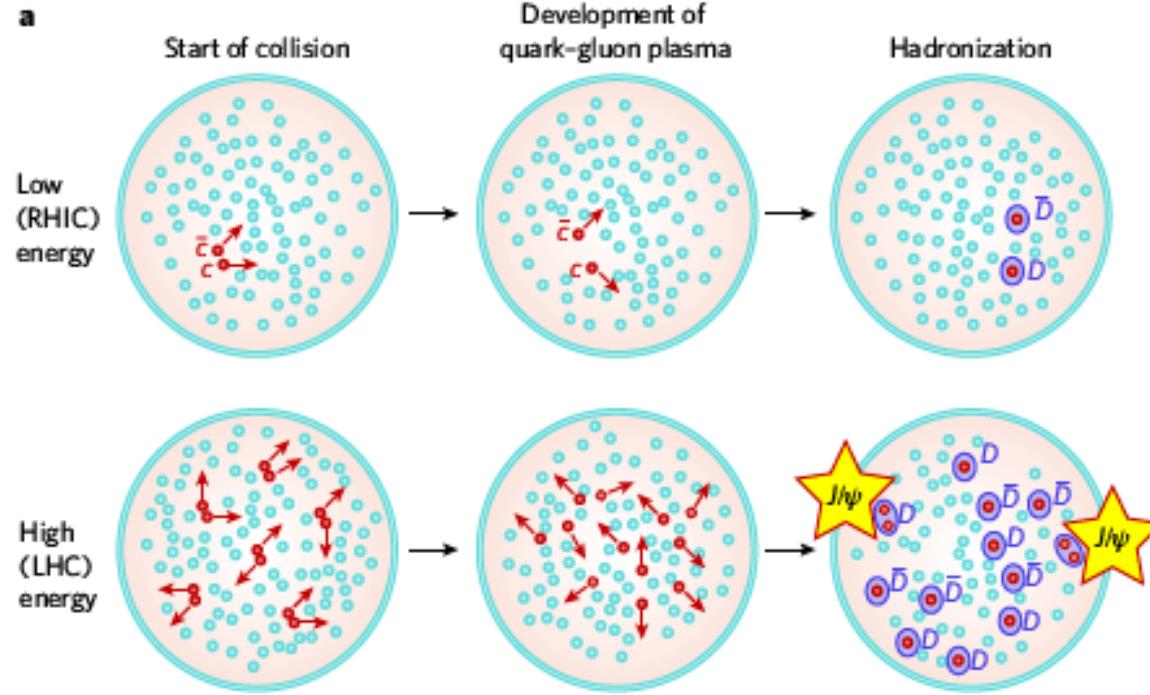
and for $N_{c,\bar{c}} \ll 1 \rightarrow$ canonical: $N_{c\bar{c}}^{dir} = \frac{1}{2} g_c N_{oc}^{therm} \frac{I_1(g_c N_{oc}^{therm})}{I_0(g_c N_{oc}^{therm})}$

obtain: $N_D = N_D^{therm} \cdot g_c \cdot \frac{I_1}{I_0}$ and $N_{J/\psi} = N_{J/\psi}^{therm} \cdot g_c^2$ and same for all other charmed hadrons

additional input parameters (beyond T, μ_b)
fixed by fitting light flavor hadron yields: $V, N_{c\bar{c}}^{direct}$

- volume V fixed by $dN_{ch}/d\eta$
- $N_{c\bar{c}}^{direct}$ from pQCD as long as precision data are lacking
- causally connected region – use 1 unit y (but tested a range)
- core-corona: treat overlap with the tails of nuclear density distribution as pp physics

quarkonium as a probe for deconfinement at the LHC the statistical hadronization picture

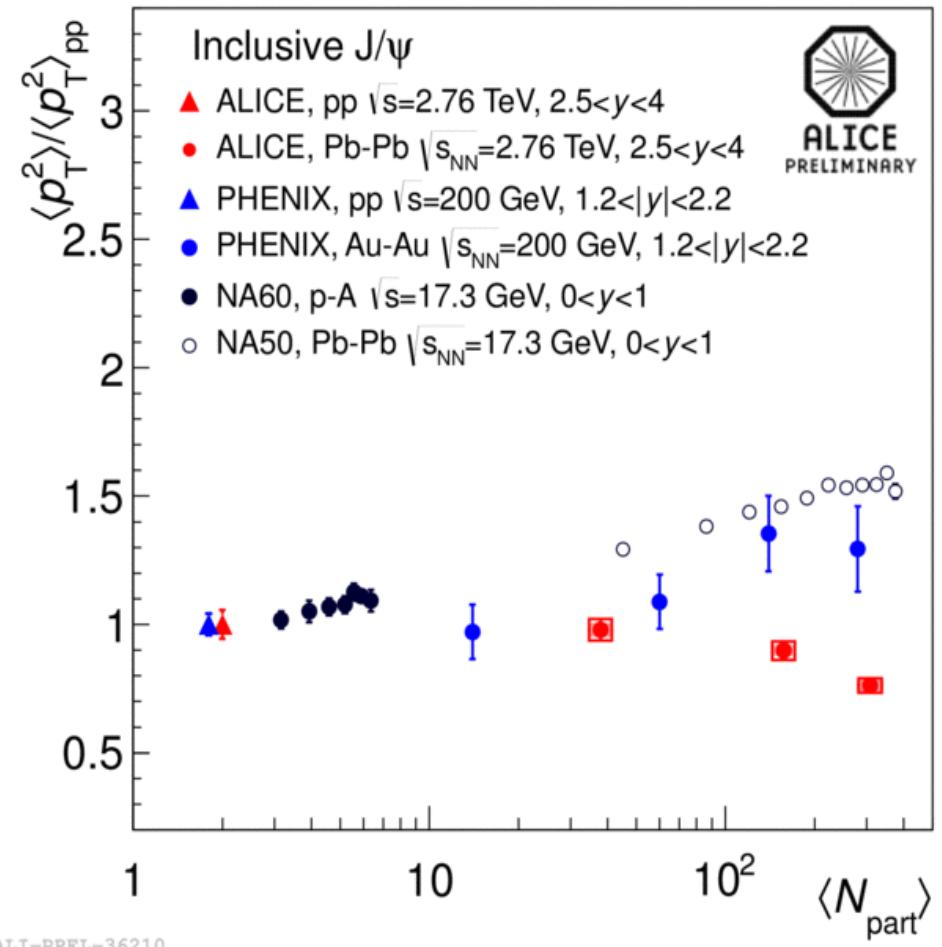
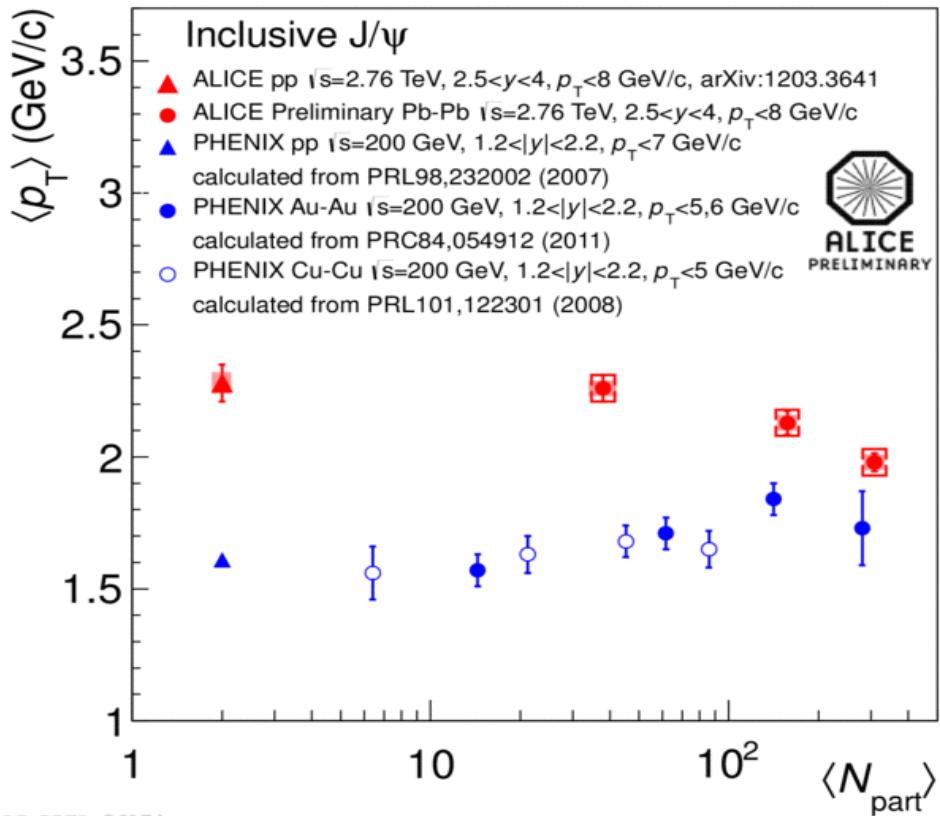


charmonium enhancement as fingerprint of deconfinement at LHC energy
only free parameter: open charm cross section in nuclear collision

Braun-Munzinger, J.S., Phys. Lett. B490 (2000) 196 and

Andronic, Braun-Munzinger, Redlich, J.S., Phys. Lett. B652 (2007) 659

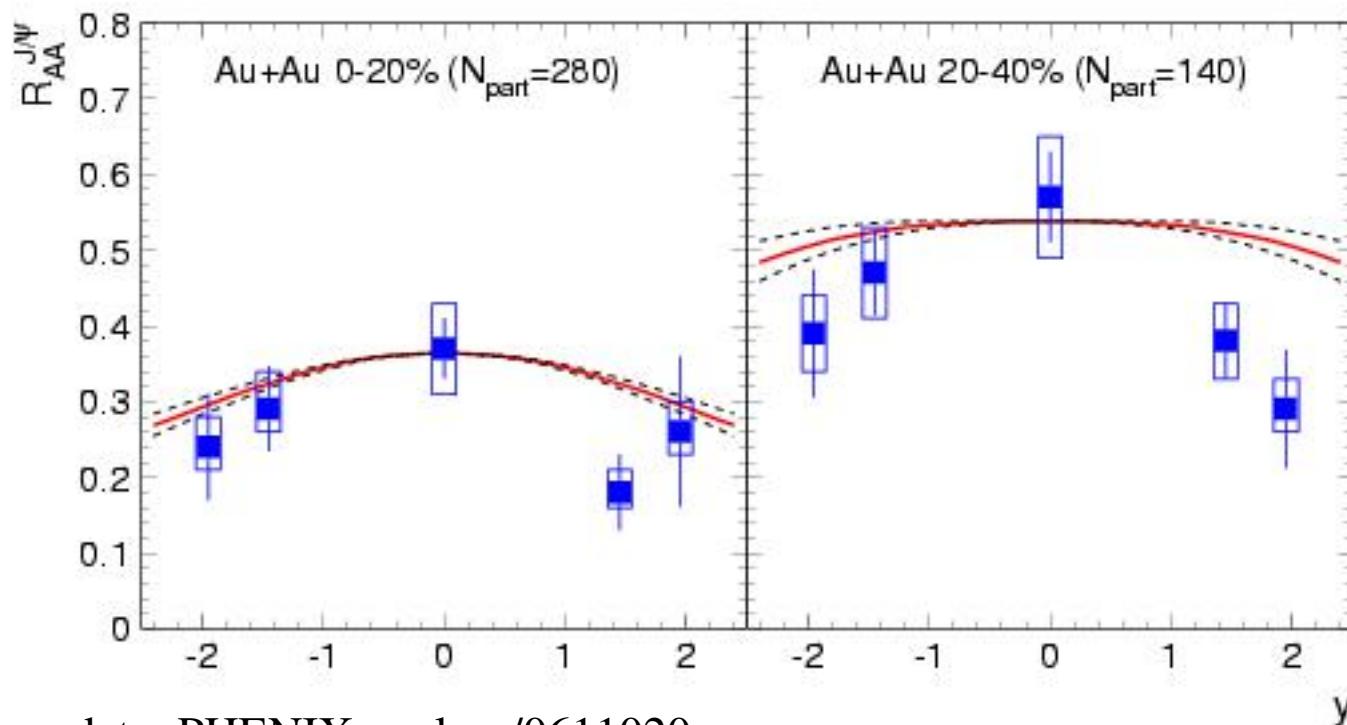
softening of J/psi p_t distributions for central PbPb coll.



At LHC for central collisions softening relative to peripheral collisions and relative to pp (opposite trend to RHIC) - consistent with formation of J/psi from thermalized c-quarks

comparison of model predictions to RHIC data:

$R_{AA}^{J/\psi}$: J/ψ yield in AuAu / J/ψ yield in pp times N_{coll}



data: PHENIX nucl-ex/0611020

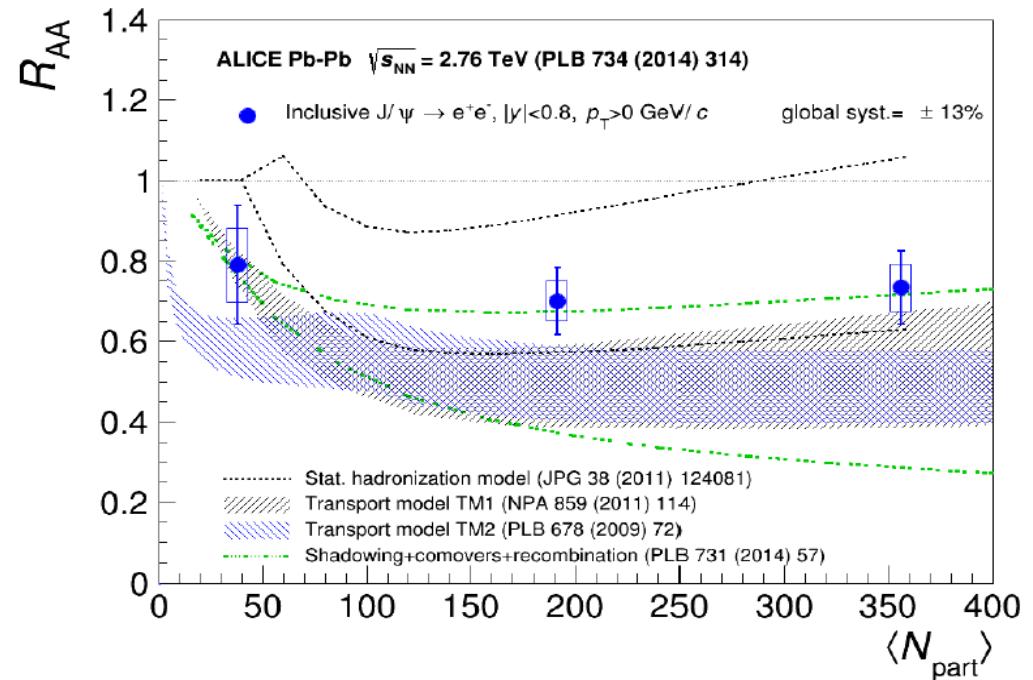
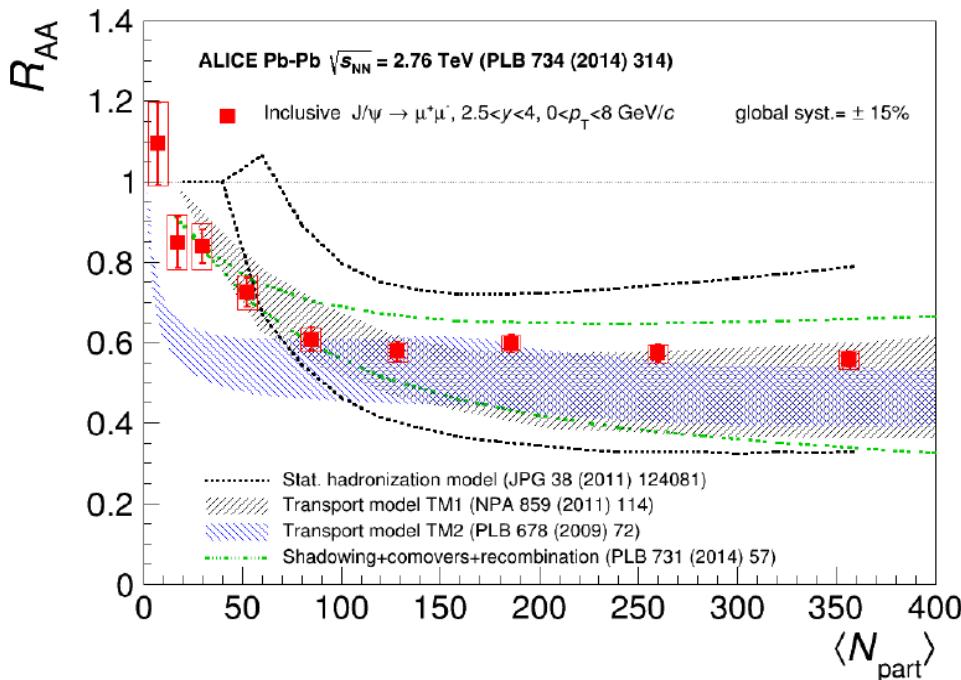
additional 14% syst error beyond shown

model: A. Andronic, P. Braun-Munzinger, K. Redlich,
J. Stachel Phys. Lett. B652 (2007) 259

good agreement, no free parameters
same holds for centrality dependence

remark: y -dep **opposite** in 'normal Debye screening' picture; suppression strongest at midrapidity (largest density of color charges)

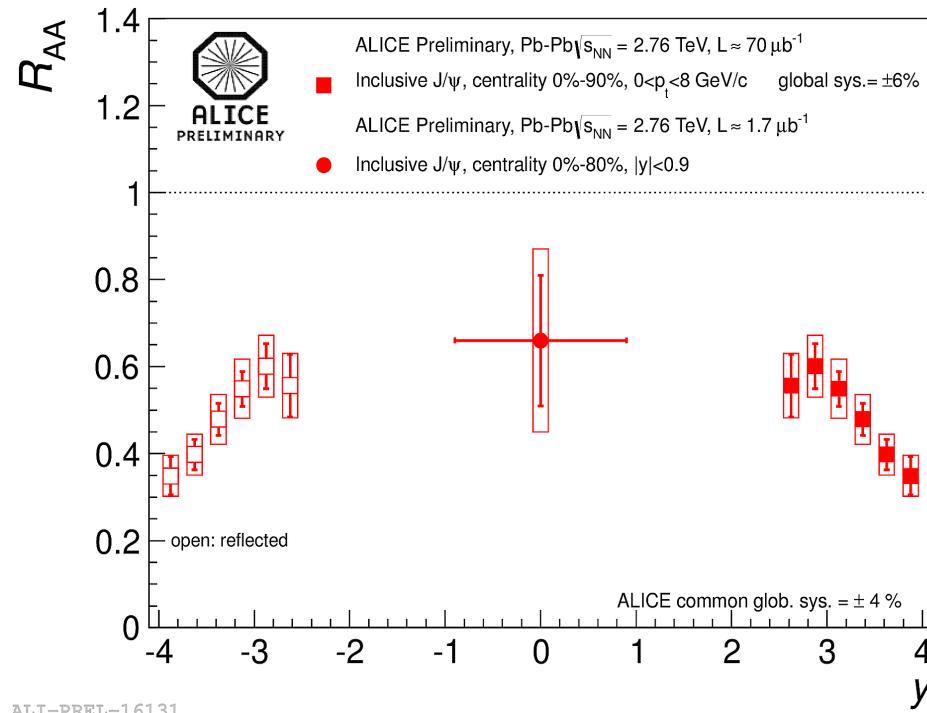
J/psi and transport models (and stat hadronization)



in transport models (Rapp et al. & Zhuang et al.) J/ψ generated both in QGP and at hadronization

- transport models also in line with R_{AA}
part of J/ψ from direct hard production, part dynamically generated in QGP, part at hadronization, but different open charm cross section used
(0.5-0.75mb TAMU and 0.65-0.8 mb Tsinghua vs. 0.3-0.4 mb SHM) **more below**

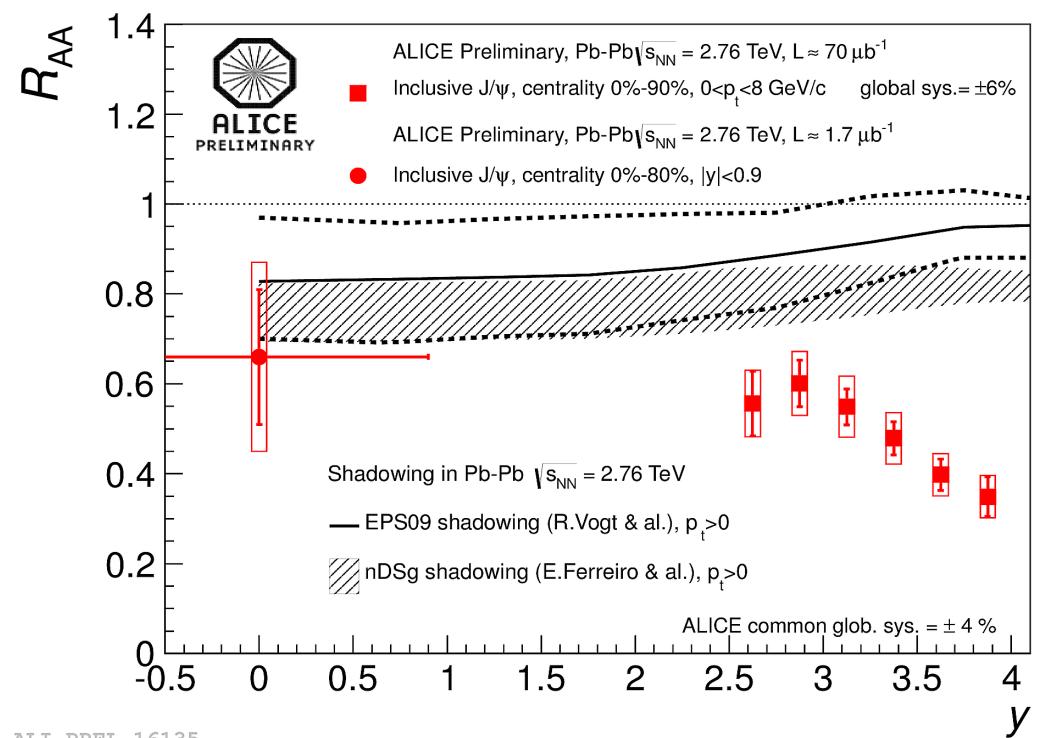
rapidity dependence of J/psi R_{AA}



ALI-PREL-16131

comparison to shadowing calculations:
 - at mid-rapidity suppression could be explained by shadowing only
 - at forward rapidity there seems to be additional suppression
 - need to measure shadowing

for statistical hadronization J/ψ yield proportional to N_c^2
 higher yield at mid-rapidity predicted in line with observation

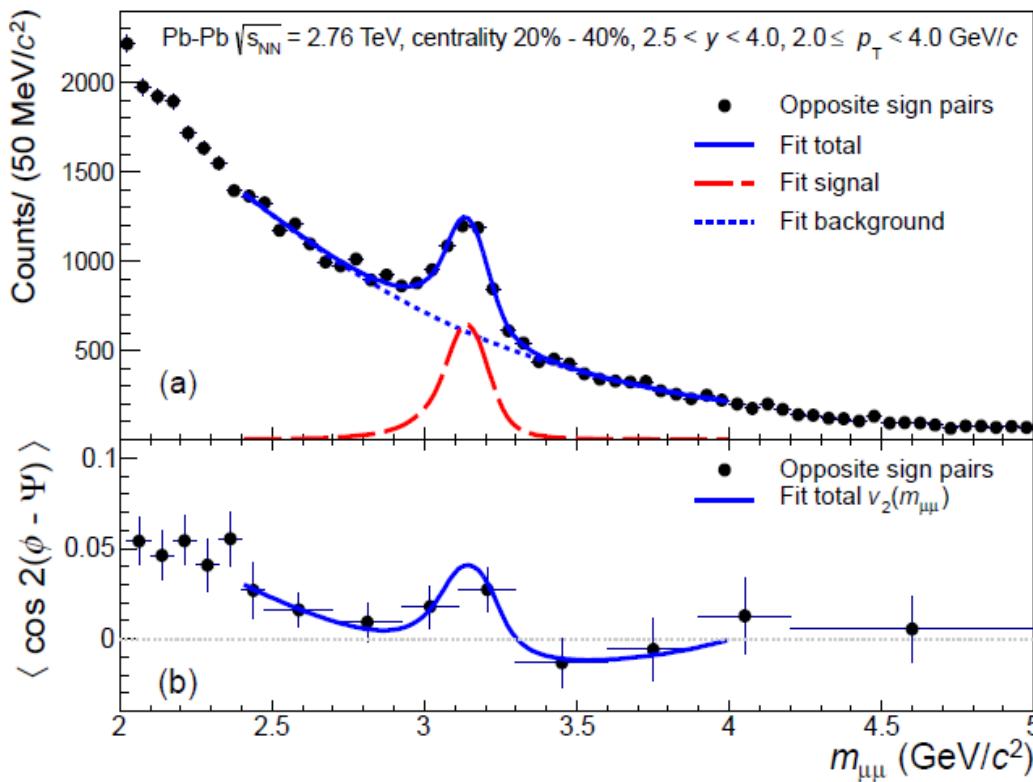


ALI-PREL-16135

elliptic flow of J/psi

charm quarks thermalized in the QGP should exhibit the elliptic flow generated in this phase

ALICE data analysis in 4 centrality bins



Centrality	$\langle N_{\text{part}} \rangle$	EP resolution $\pm (\text{stat.}) \pm (\text{syst.})$
5%-20%	283 ± 4	$0.548 \pm 0.003 \pm 0.009$
20%-40%	157 ± 3	$0.610 \pm 0.002 \pm 0.008$
40%-60%	69 ± 2	$0.451 \pm 0.003 \pm 0.008$
60%-90%	15 ± 1	$0.185 \pm 0.005 \pm 0.013$
20%-60%	113 ± 3	$0.576 \pm 0.002 \pm 0.008$

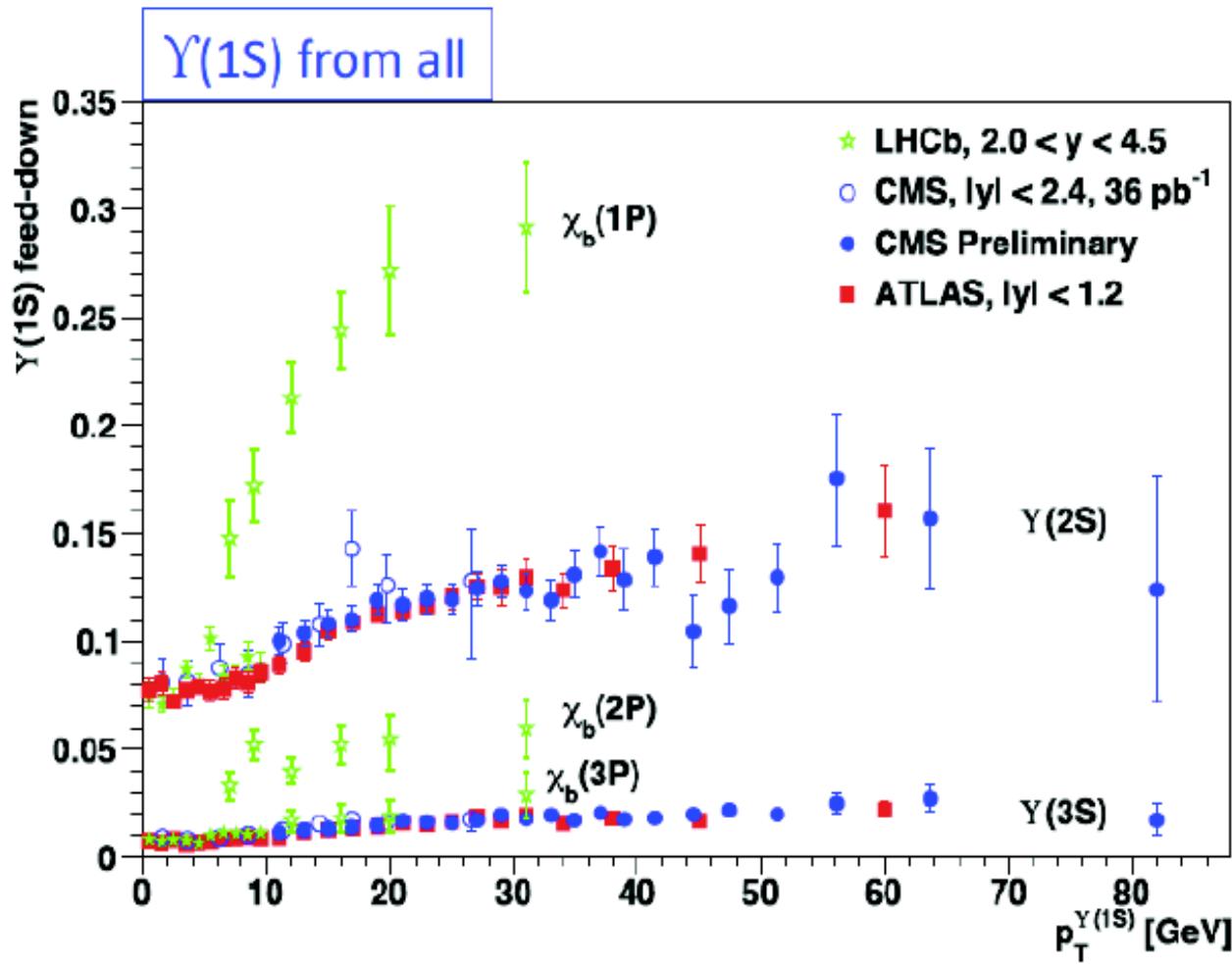
analyze opposite sign muon pairs relative to the V0 event plane as function of mass and for each pt bin

- fit distribution with

$$v_2(m_{\mu\mu}) = v_2^{\text{sig}} \alpha(m_{\mu\mu}) + v_2^{\text{bkg}}(m_{\mu\mu}) [1 - \alpha(m_{\mu\mu})]$$

where $\alpha(m_{\mu\mu}) = S / (S+B)$ fitted to the mass spectrum

Feeding into Upsilon (1S)



outlook – what ALICE can do in the future

LHC run1:

2 PbPb runs

- 2010 $O(10 \mu b^{-1})$
- 2011 $O(150 \mu b^{-1})$

luminosity reached $\mathcal{L}=2 \cdot 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$ twice design lumi at this energy

1 pPb run

- 2012/2013 $O(30 \text{ nb}^{-1})$

from 2/2013 until end of 2014 LS1: consolidation of LHC to allow full energy

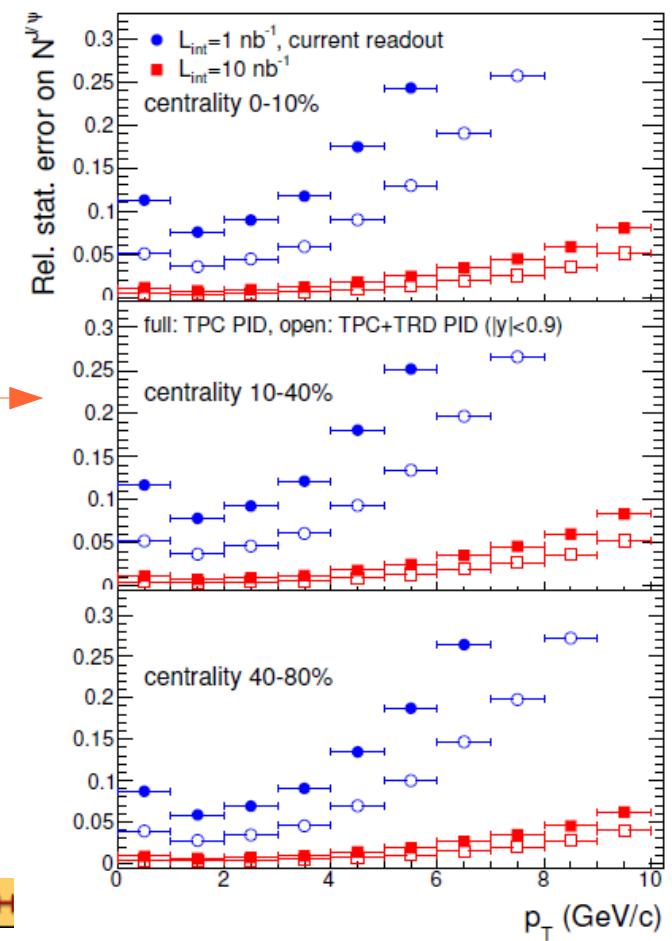
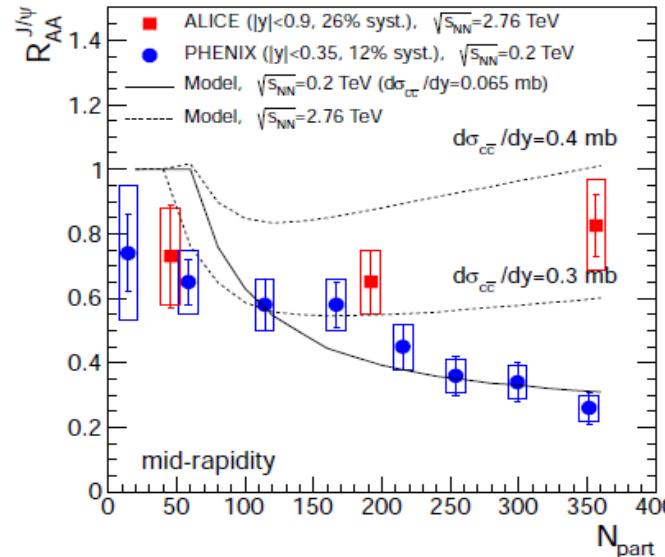
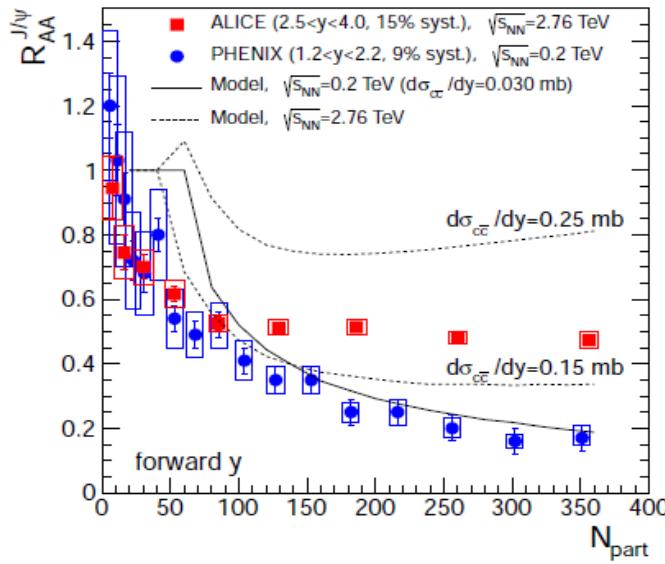
LHC run2: 2015-2018 PbPb running at $\sqrt{s_{\text{NN}}} = 5.5 \text{ TeV}$

to achieve approved initial goal of 1 nb^{-1}

late 2018 start LS2 – increase of LHC luminosity und experiment upgrade

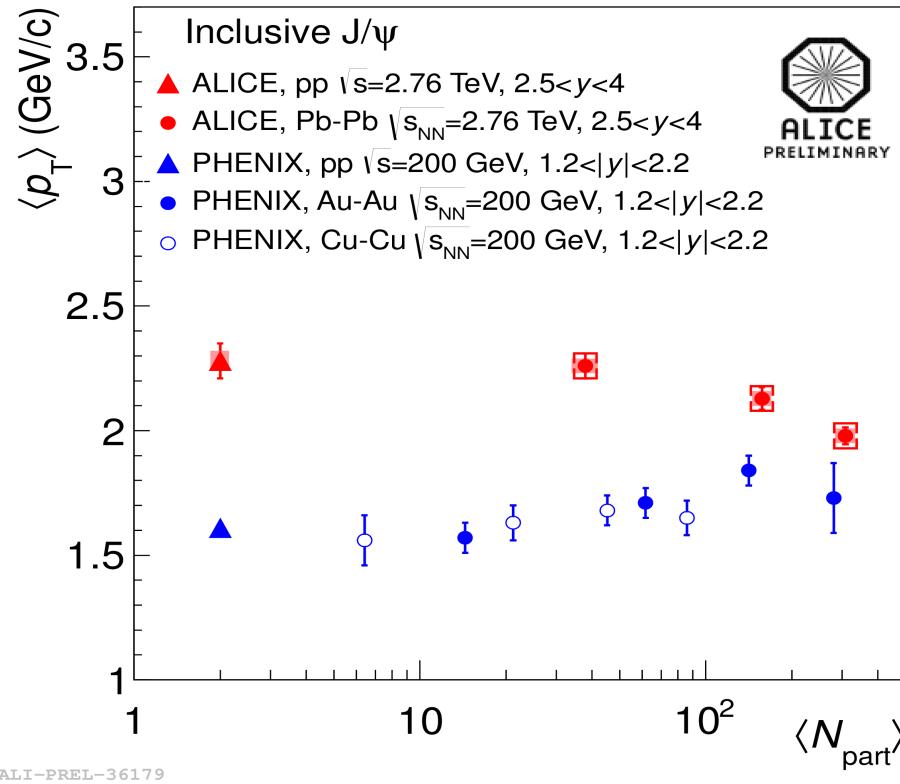
LHC run3: 2020 onwards - expect $\mathcal{L}=6 \cdot 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$ or PbPb interactions at 50 kHz
achieve for PbPb 10 nb^{-1} corresponding to $8 \cdot 10^{10}$ collisions sampled
plus a low field run of 3 nb^{-1} + pp reference running + pPb - a program for about 6 years

J/psi as probe of deconfinement

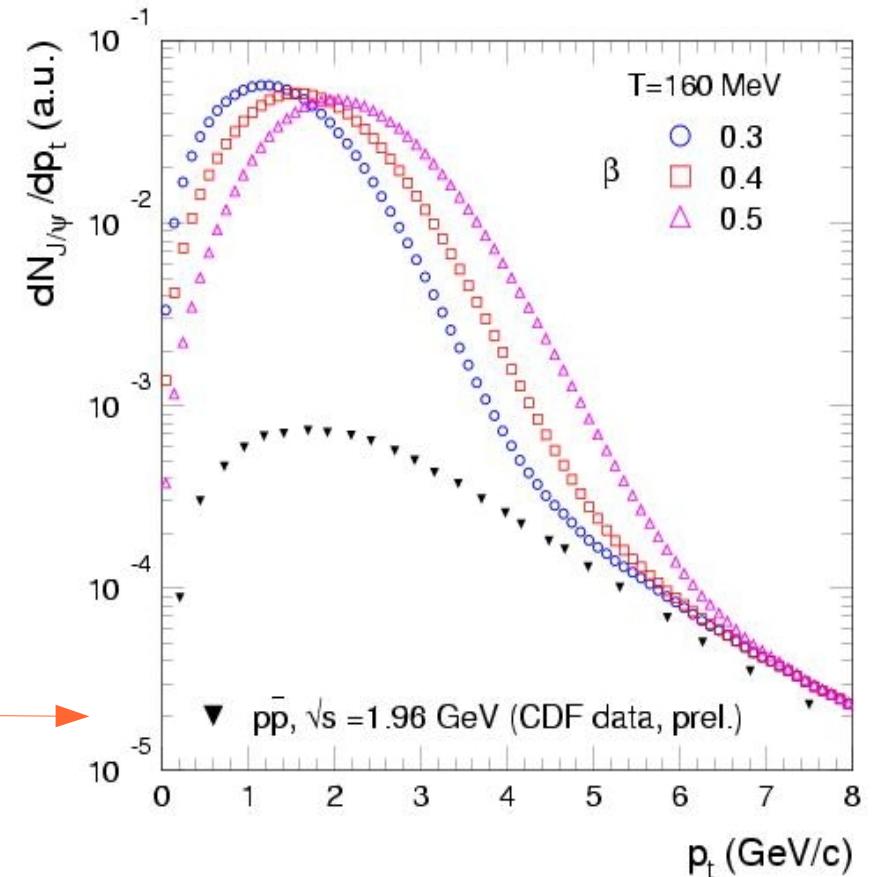


di-electrons statistics limited, 10 nb^{-1} will have huge effect
 but also syst uncertainties will decrease with upgrade:
 will also add TRD for electron id - reduced comb background
 thinner ITS reduced radiation tail
 both affect signal extraction

spectral distribution is key to thermalization

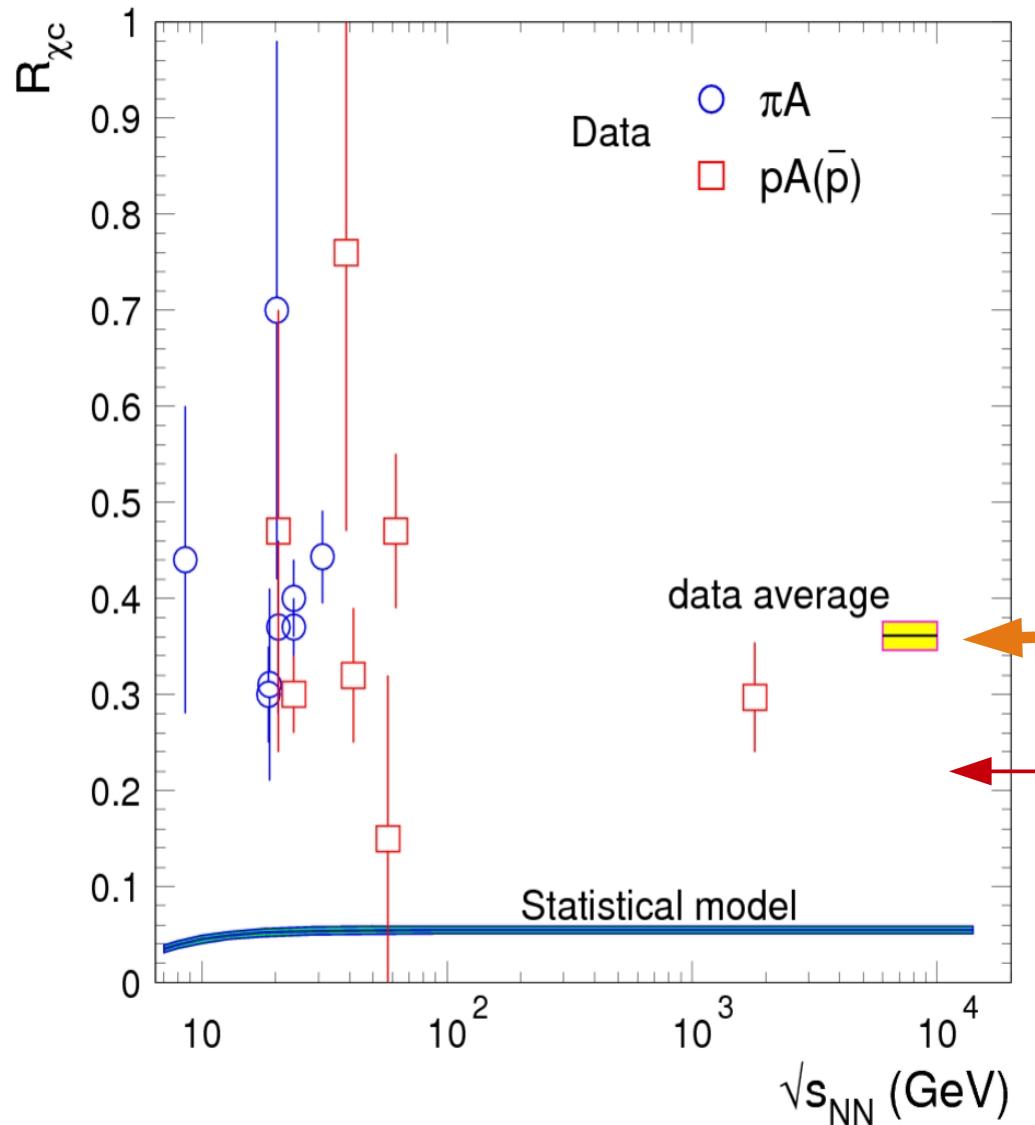


at LHC shift of paradigm: more central collision → narrower momentum distribution
my interpretation: thermalization



but if charm quark thermalize, their spectral distributions should also reflect collective flow of liquid

situation even more dramatic for P-states

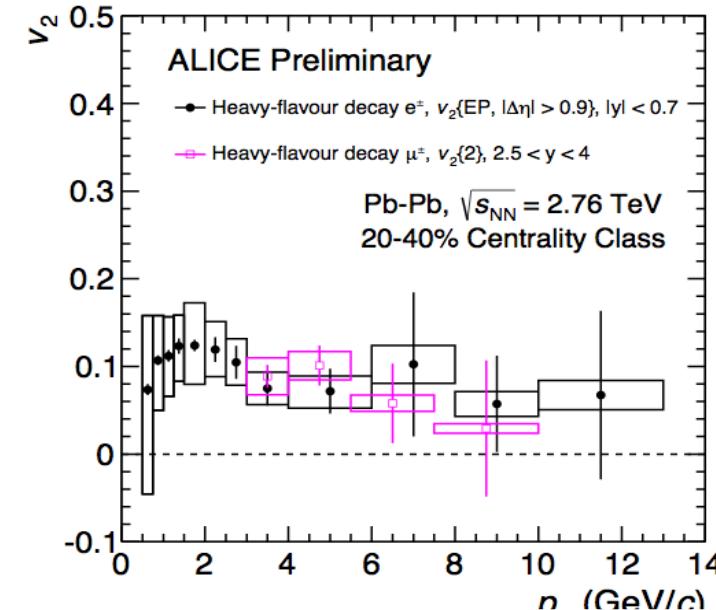
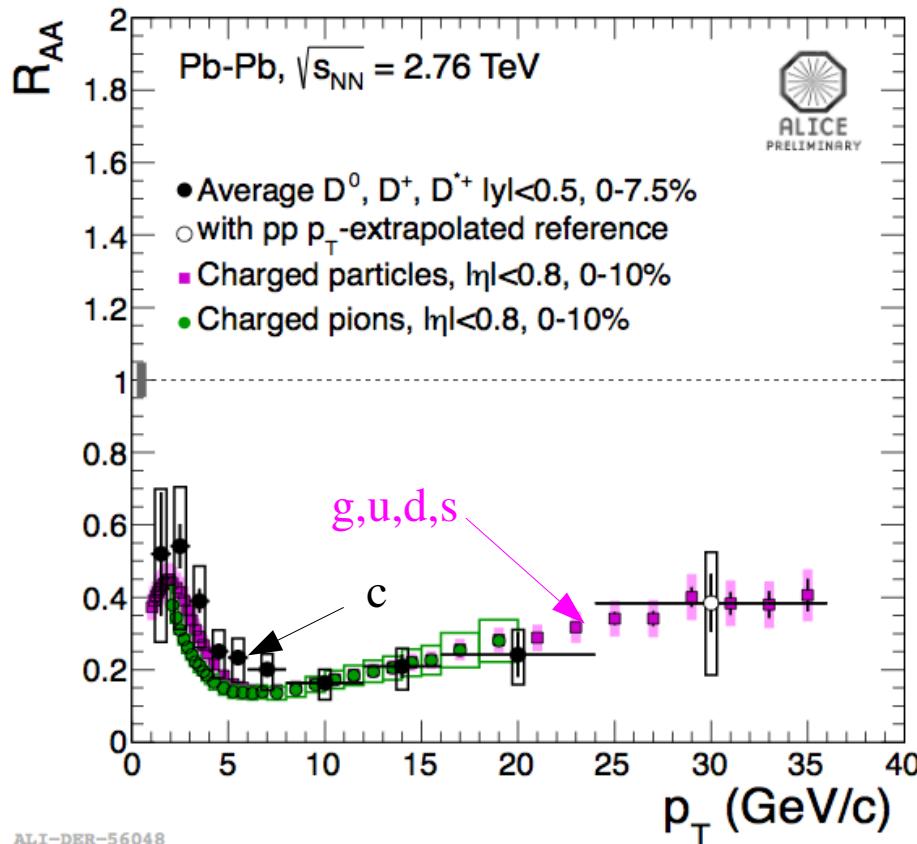


pA and πA data on average factor
7 above statistical model prediction

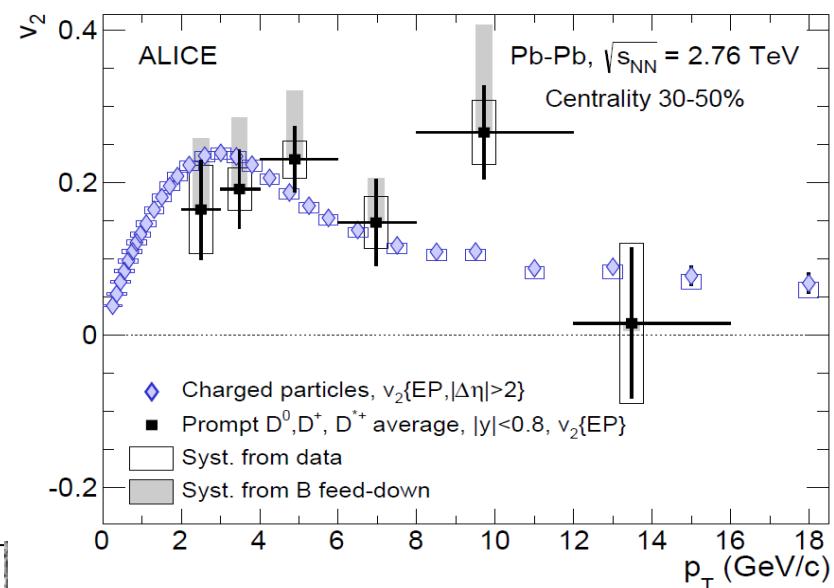
Transport model (Rapp)

Charm quarks thermalize to large degree in QGP

strong energy loss of charm quarks

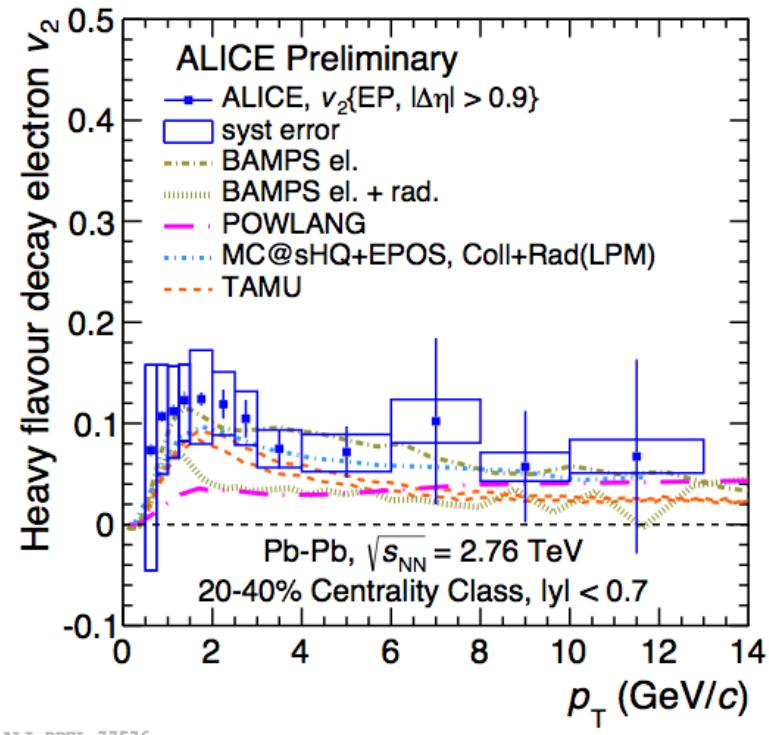
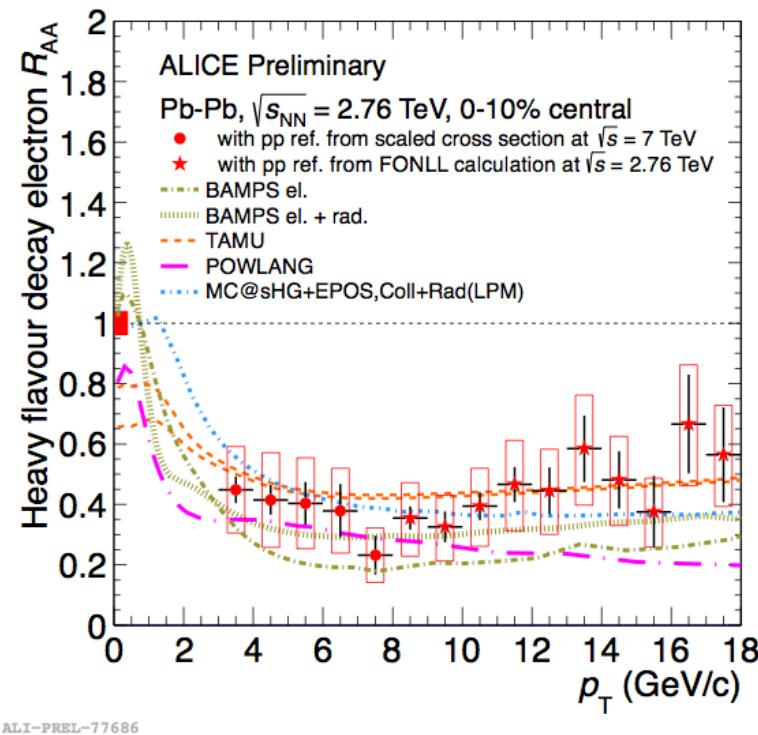


elliptic flow for charm – participation in coll. flow

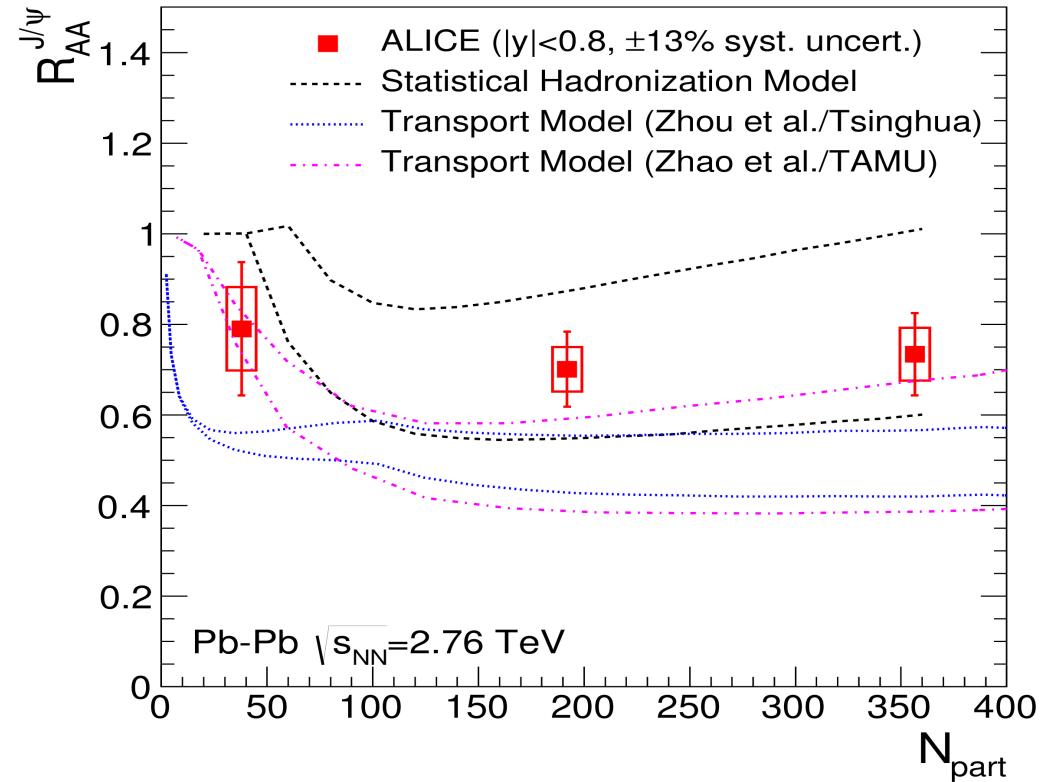
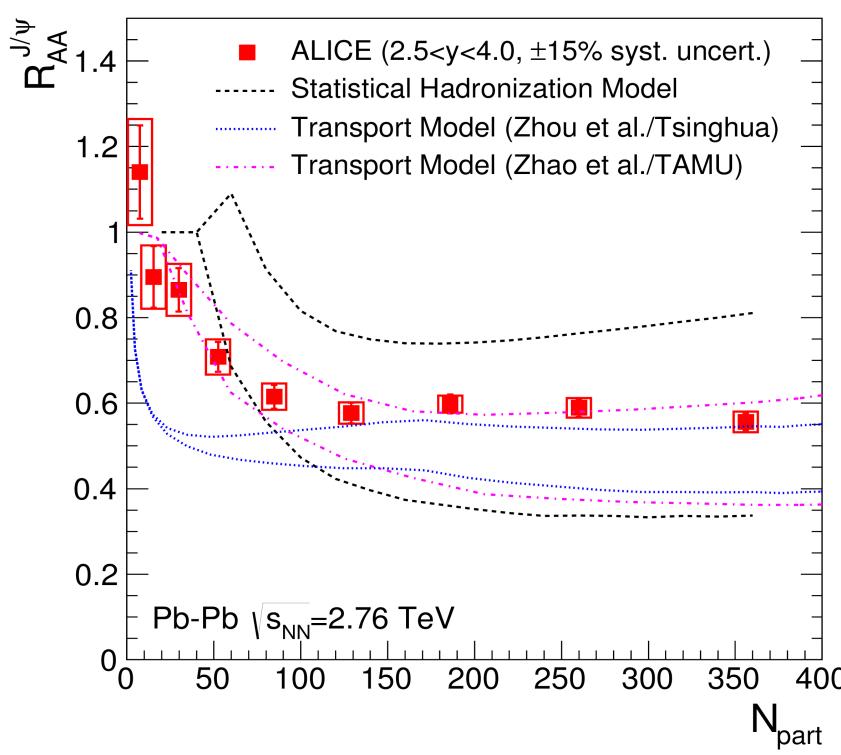


M.Djordjevic, arXiv:1307.4098:
equal R_{AA} is a conspiracy of different
fragmentation functions of light quarks,
gluons, charm and different color factors in
energy loss

models constrained by simultaneous fit of R_{AA} and v_2

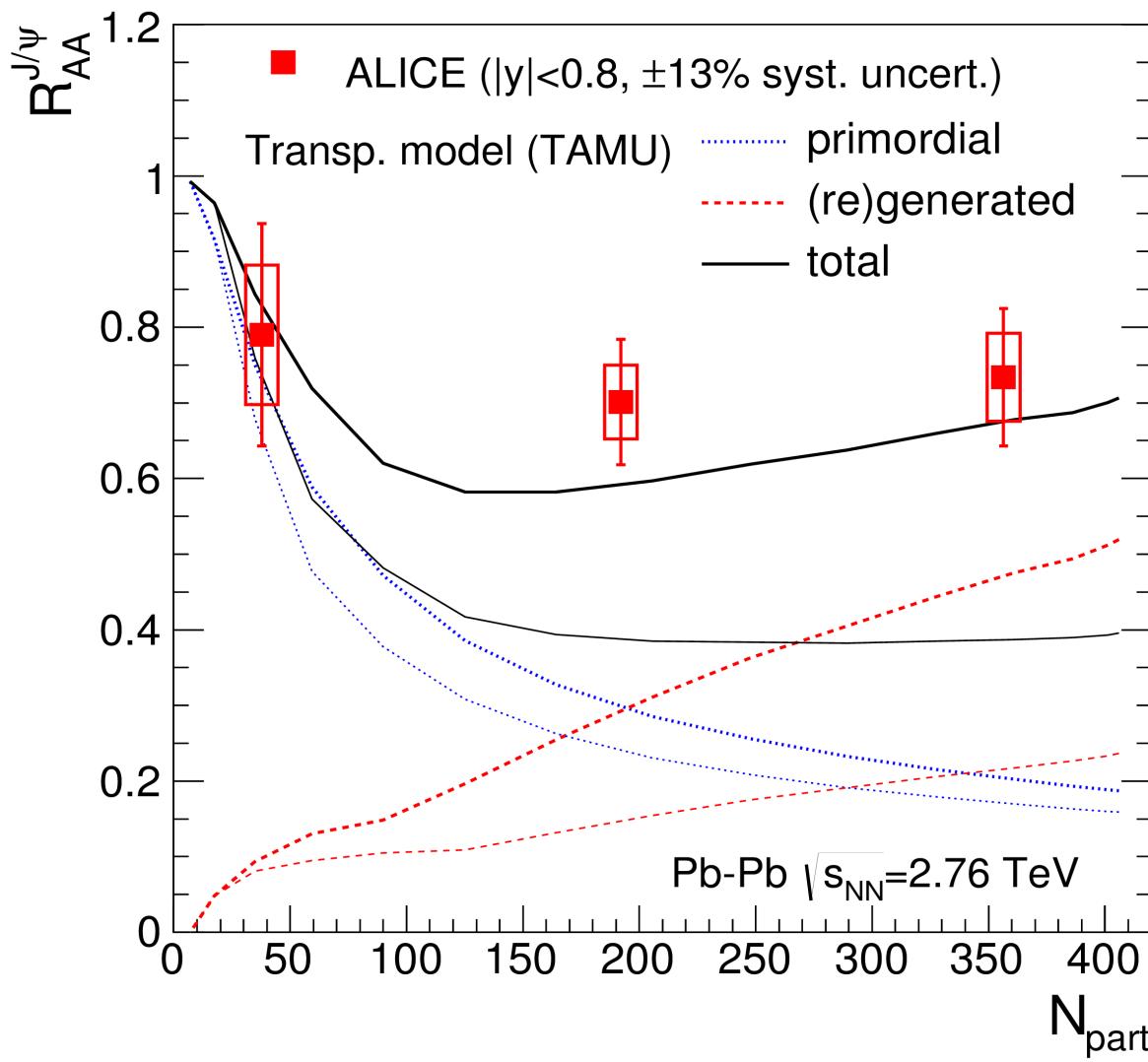


J/psi and transport models (and stat hadronization)



in transport models (Rapp et al. & P.Zhuang, N.Xu et al.) J/psi generated both in QGP and at hadronization

- transport models also in line with R_{AA}
part of J/psi from direct hard production, part dynamically generated in QGP, part at hadronization, **but different open charm cross section used**
(0.5-0.75mb TAMU and 0.65-0.8 mb Tsinghua vs. 0.3-0.4 mb SHM)



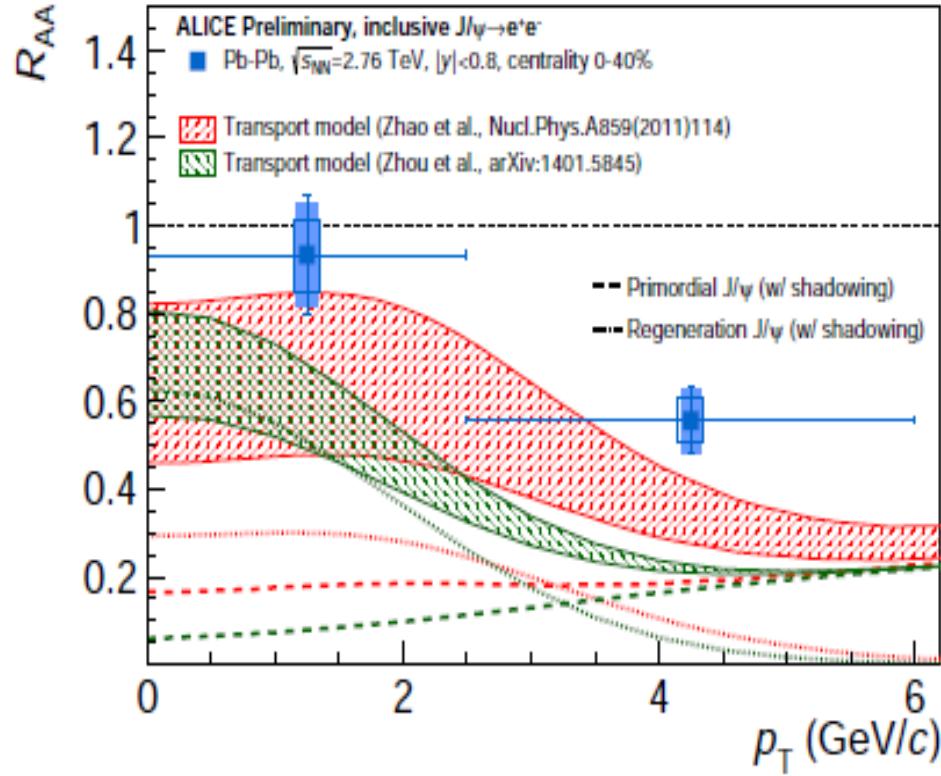
TAMU transport model:

Zhao et al., NPA 859 (2011) 114 and priv. comm.

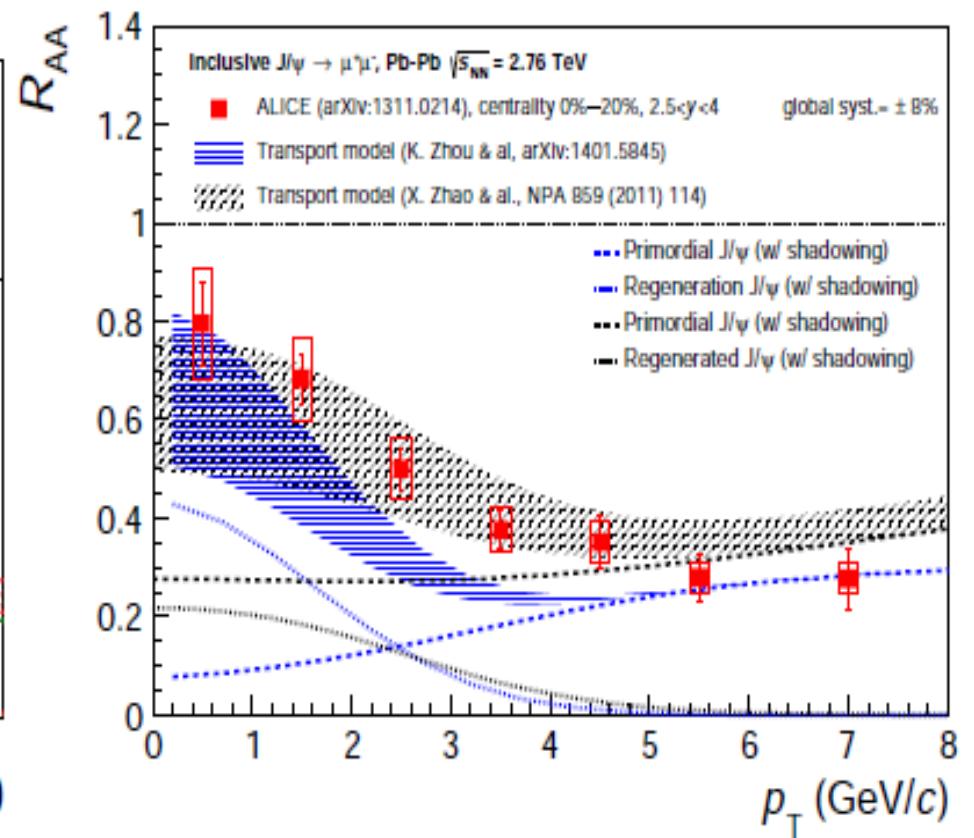
similar fractions in the Tsinghua model

comparison with (re-)generation models

midrapidity



forward rapidity



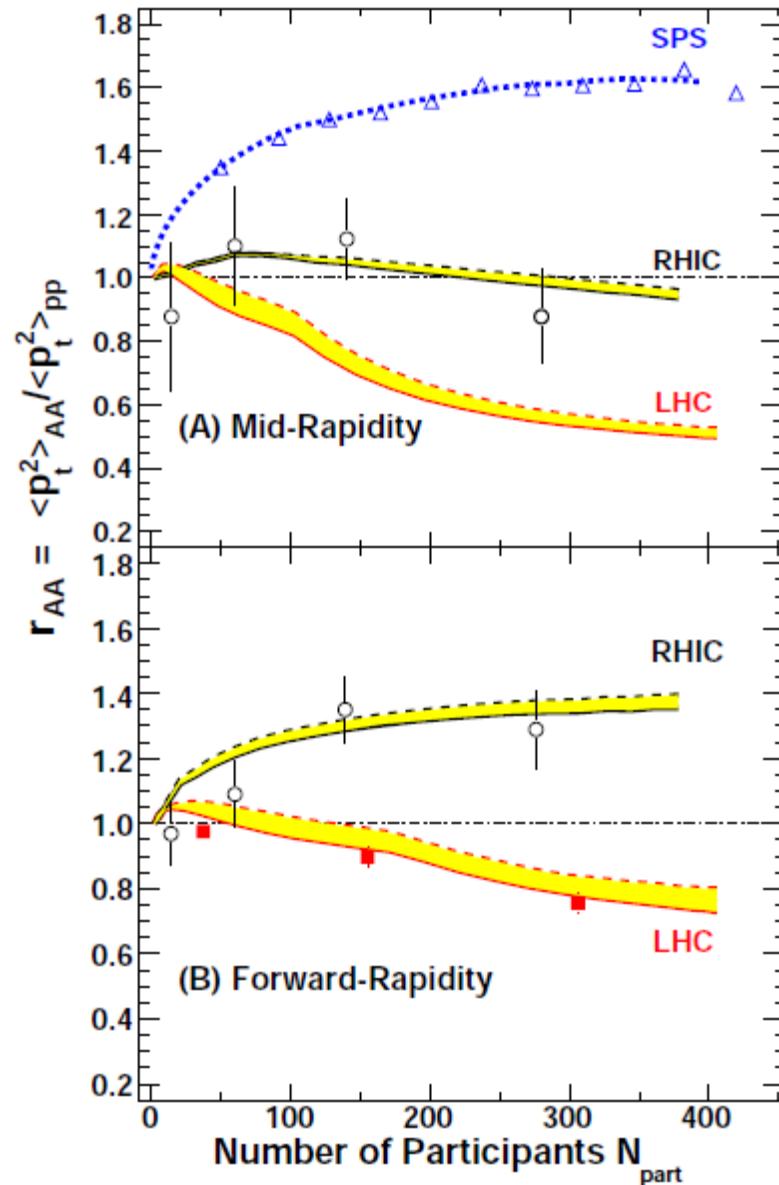
good agreement lends further strong support to the
 'full color screening and late J/ψ production' picture

analysis of transverse momentum spectra

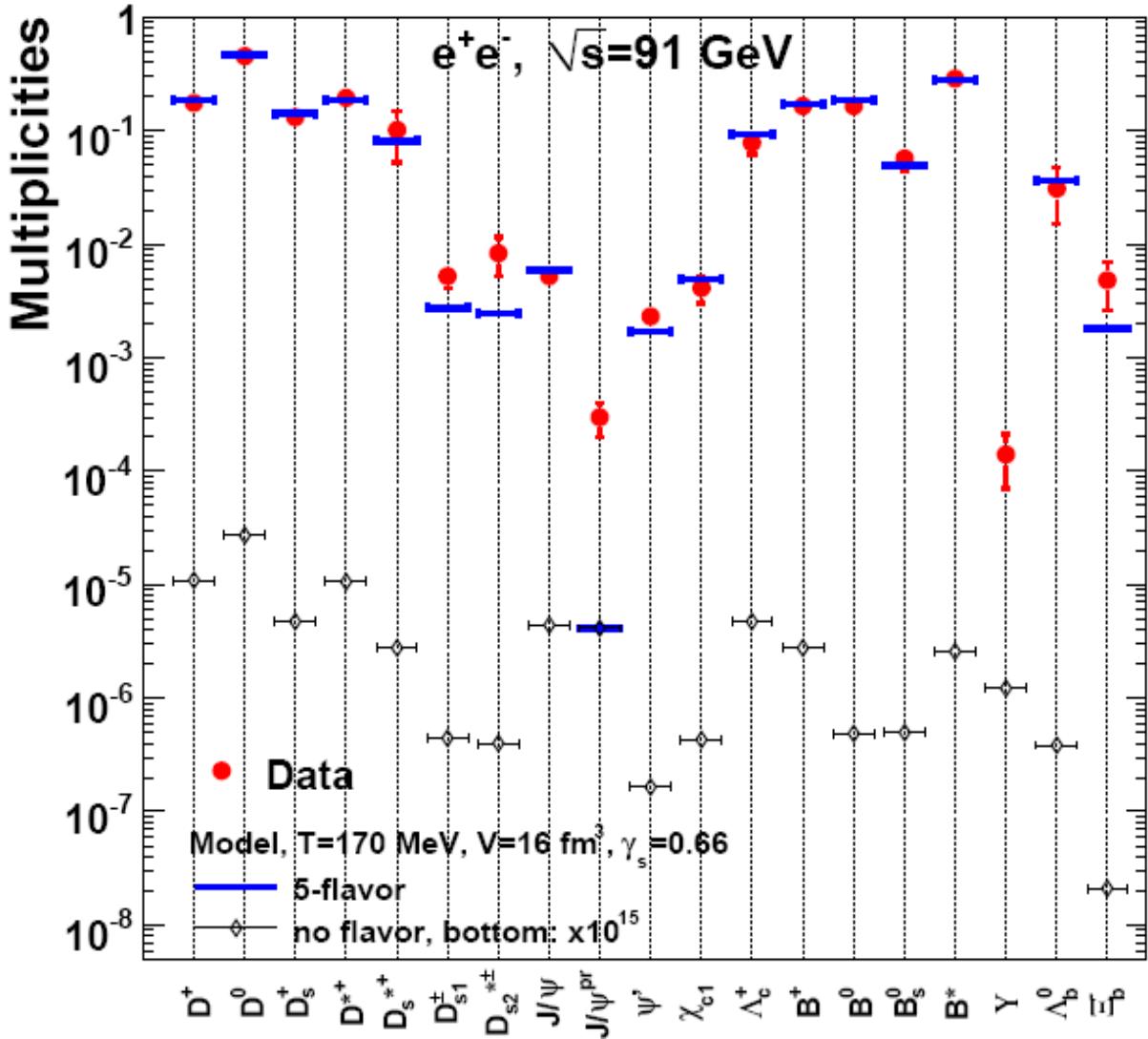
arXiv:1309.7520v1 [nucl-th] 29 Sep 2013

Zhou, Xu, Zhuang

at LHC energy, mostly (re-) generation of charmonium, p_t distribution exhibits features of strong energy loss and approach to thermalization for charm quarks



heavy quark and quarkonium production in e+e- collisions



Comparison of stat.
model calcs.
with data

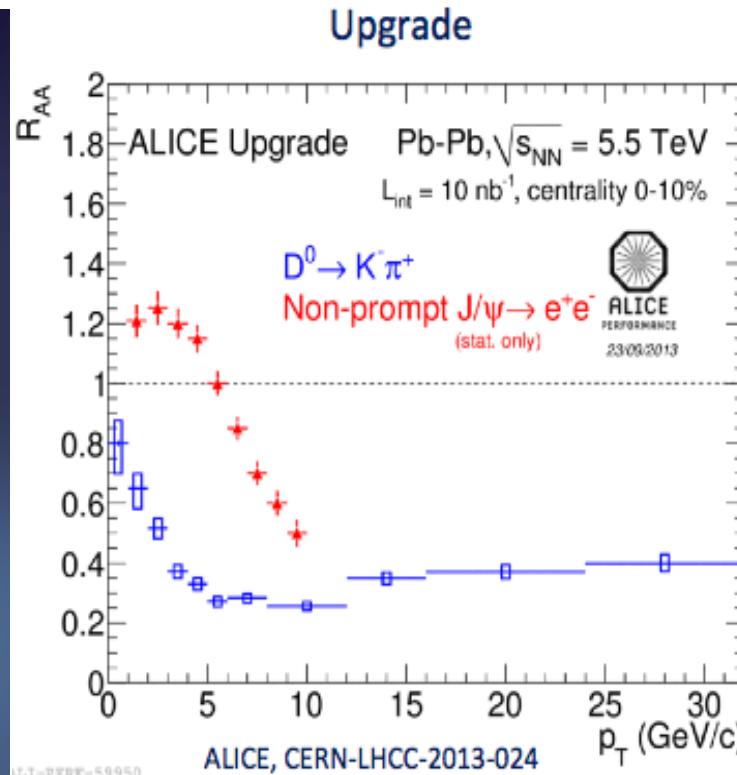
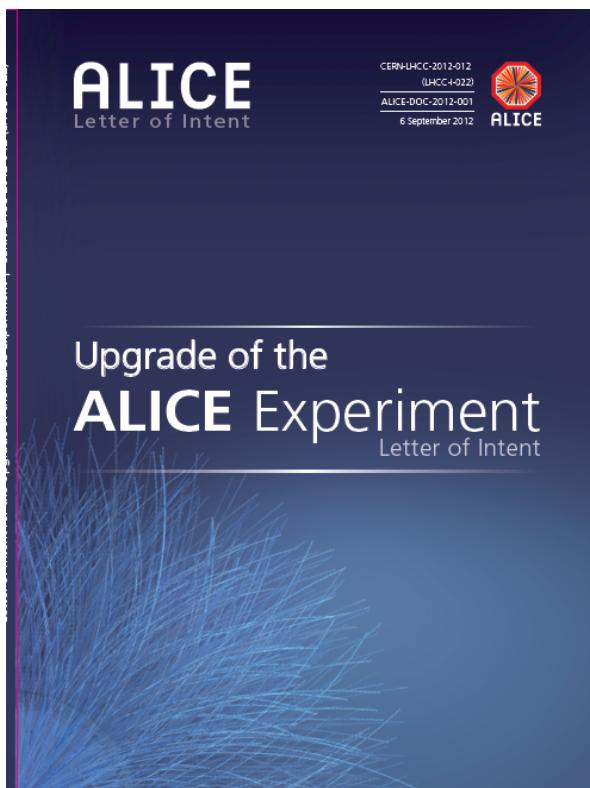
Phys. Lett. B678 (2009) 350,
arXiv:0903.1610 [hep-ph]

charmonium cannot be
described
at all in this approach

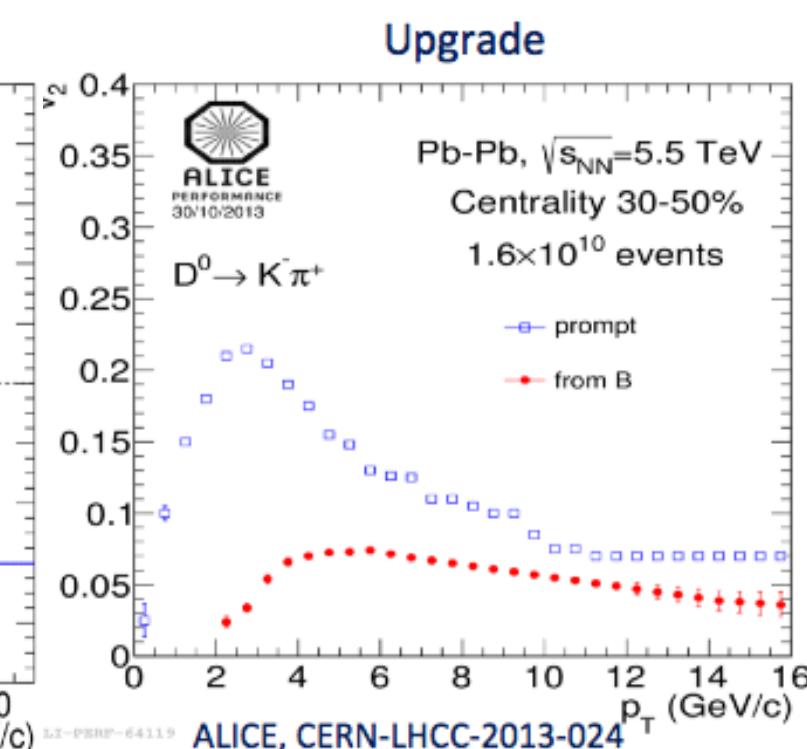
But: all charm quarks
hadronize
at 170 MeV

outlook open heavy flavor – LHC run3

new high performance ITS plus rate increase (TPC upgrade)



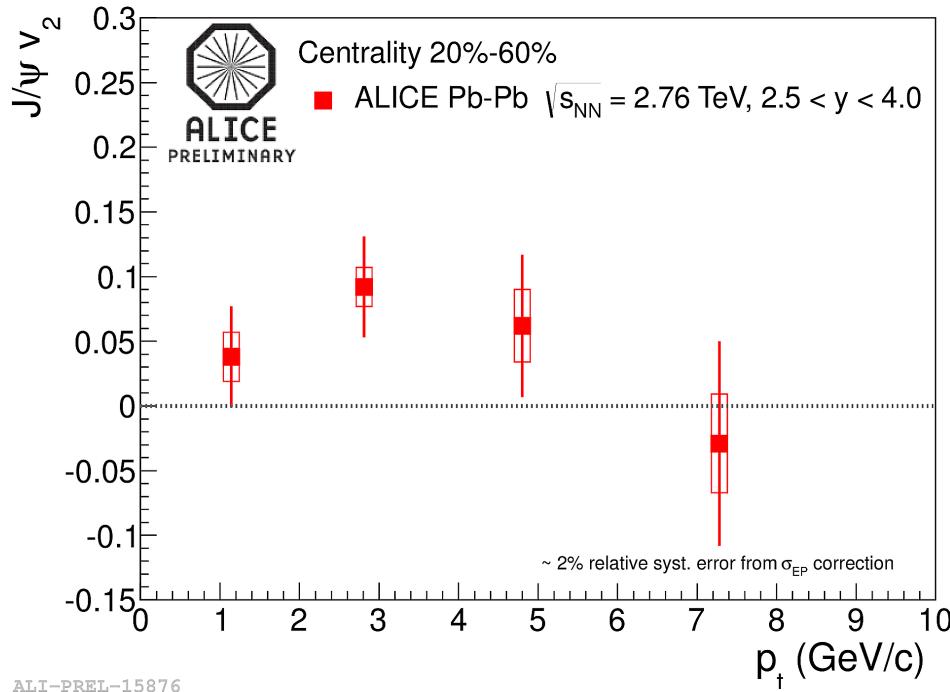
Charm and beauty R_{AA} down to $p_T \sim 0$ using D^0 and B-decay J/ψ



Input values from BAMPS model: C. Greiner et al. arXiv:1205.4945

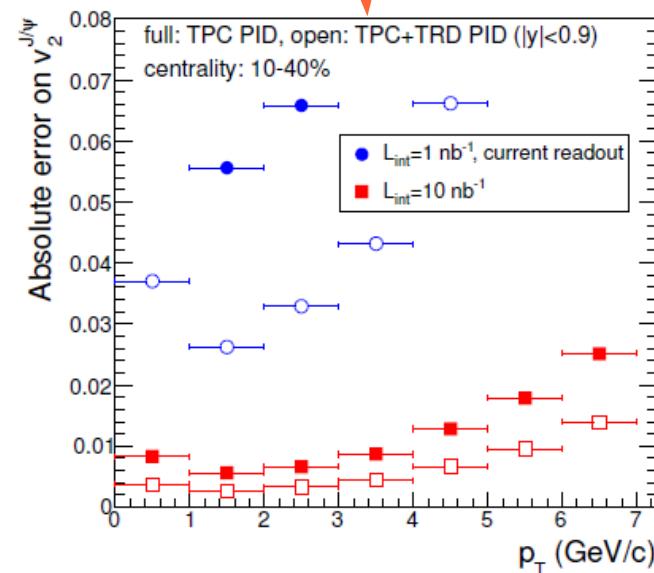
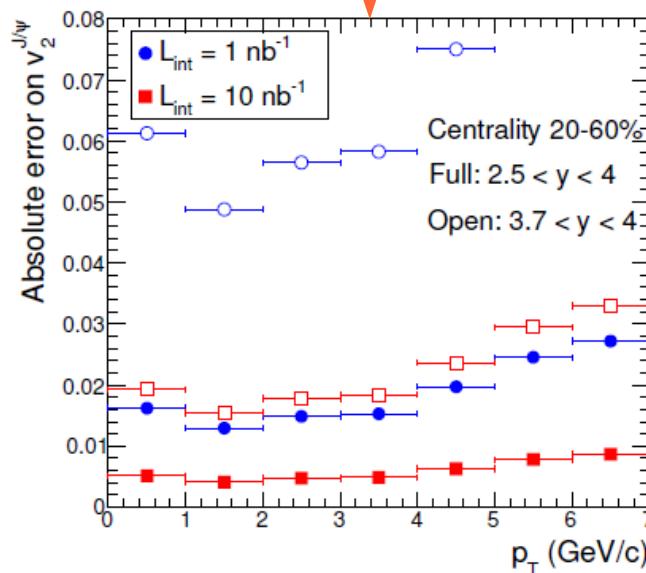
Charm v_2 down to $p_T \sim 0$ using prompt and beauty v_2 down to B
 $p_T \sim 0$ using B-decay D^0

J/psi elliptic flow



observation of flow with muon arm
presently 3 sigma
needs statistics to make model comparison
meaningful

future statistical errors
muon arm central barrel



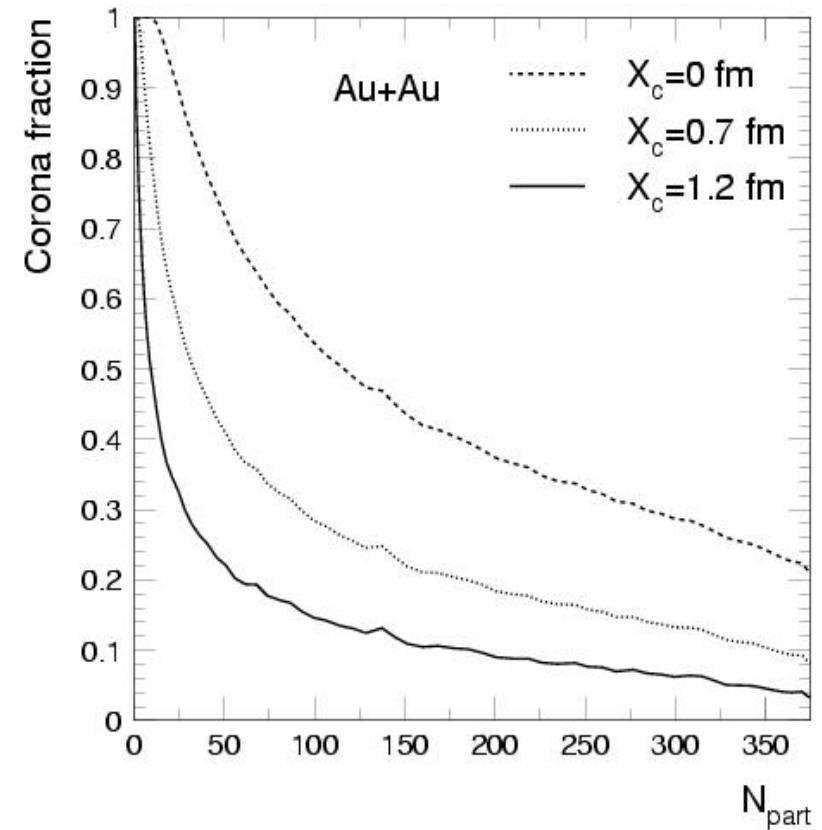
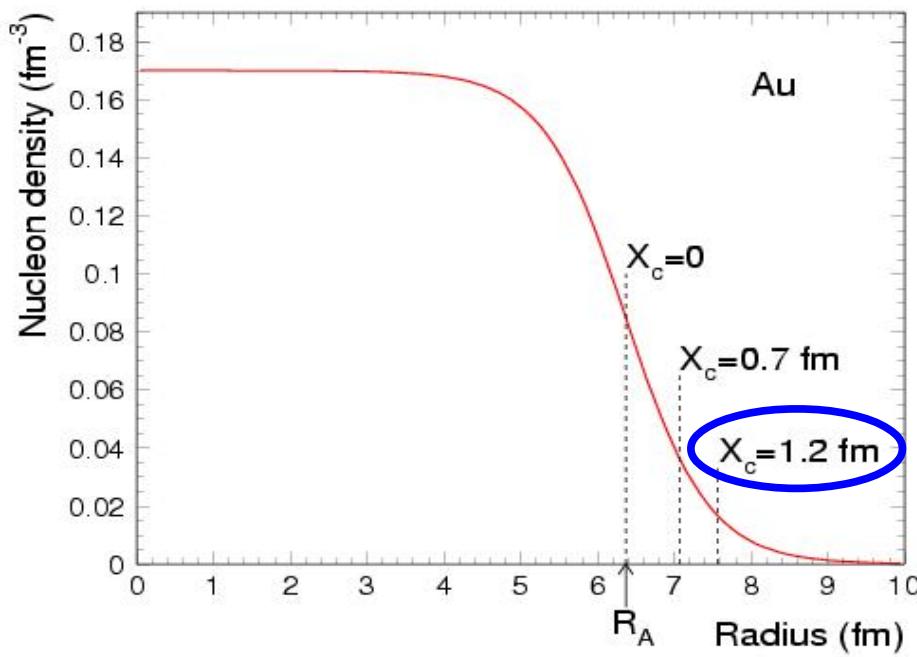
physics reach after ALICE upgrade

Topic	Observable	Approved (1/nb delivered, 0.1/nb m.b.)	Upgrade (10/nb delivered, 10/nb m.b.)
Heavy flavour	D meson RAA	pT>1, 10%	pT>0, 0.3%
	D from B RAA	pT>3, 30%	pT>2, 1%
	D meson elliptic flow (for v2=0.2)	pT>1, 50%	pT>0, 2.5%
	D from B elliptic flow (for v2=0.1)	not accessible	pT>2, 20%
	Charm baryon/meson ratio (Λ_c/D)	not accessible	pT>2, 15%
Charmonia	Ds RAA	pT>4, 15%	pT>1, 1%
	J/ψ RAA (forward y)	pT>0, 1%	pT>0, 0.3%
	J/ψ RAA (central y)	pT>0, 5%	pT>0, 0.5%
	J/ψ elliptic flow (forward y, for v2 =0.1)	pT>0, 15%	pT>0, 5%
	ψ'	pT>0, 30%	pT>0, 10%
Dielectrons	Temperature IMR	not accessible	10% on T
	Elliptic flow IMR (for v2=0.1)	not accessible	10%
	Low-mass vector spectral function	not accessible	pT>0.3, 20%
Heavy nuclei	hyper(anti)nuclei, H-dibaryon	35% (4ΔH)	3.5% (4ΔH)

↑
stat. error at min pt

extension of statistical model to include charmed hadrons

core-corona effect considered: important for more peripheral collisions
 “core” up to $R_A + X_c$ “corona” outside



$$N_{\text{part}}(b) = N_{\text{core}}(b) + N_{\text{corona}}(b)$$

Collisions in corona region treated as in pp, core: medium, e.g. QGP

$dN_{\text{ch}}/d\eta/N_{\text{part}}(b) = dN_{\text{ch}}/d\eta/N_{\text{core}}(b) + dN_{\text{ch}}^{\text{pp}}/d\eta/N_{\text{corona}}(b)$ and same for J/psi

core-corona effect

